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A BIOLOGICAL ASSESSMENT OF HAWAIIAN

BOTTOM FISH STOCKS, 1984-87

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ABSTRACT

The Honolulu wholesale market for bottom fish was studied to assess the condition of the Hawaiian bottom fishery and to determine the status of the stocks. Although a wide variety of species are sold as bottom fish, we identify 12 principal species in the Hawaiian fishery. Annual landings indicate that opakapaka, *Pristipomoides filamentosus*, is the single most important species in the fishery (36% by weight), and that onaga, *Etelis coruscans*, hapuupuu, *Epinephelus quernus*, and butaguchi, *Pseudocaranx dentex*, each comprise some 15-16% of the total. Bottom fish landings from the main Hawaiian Islands (MHI) have increased every year since 1984, as have catches from the Northwestern Hawaiian Islands (NWHI).

An analysis of fishing effort and catch rate shows that in 1987 the number of effective bottom fishing trips to the NWHI fell 15%, from 139 to 118 trips, despite a net increase in the number of vessels fishing (+4). The decline in fishing effort represents a reversal of what had been a 3-yr increasing trend. Catch per unit effort (CPUE) statistics show that in 1987 the CPUE of NWHI opakapaka increased for the first time since data collection began, from 1,800 lb/trip in 1986 to 2,300 lb/trip in 1987. The CPUE for combined NWHI bottom fish increased for the fourth year in a row. At present, the range and activity of the fleet suggests that all areas in the NWHI have been exploited and that little accumulated standing stock remains to be "fished up." The fishery seems to be approaching an equilibrium point of lower sustained yields.

Analyses of size structure failed to reveal any problem with the NWHI bottom fishery. In contrast, evidence is presented suggesting that some MHI species (opakapaka, ehu, uku) are growth-overfished. Likewise, a widespread pattern of harvesting undersized juvenile fish typifies MHI bottom fisheries, a destabilizing characteristic that substantially increases the likelihood of recruitment-overfishing. To counteract these developments we suggest that serious consideration be given to implementing commercial size limits, or increasing those already in place.

INTRODUCTION

In 1986, a fishery management plan (FMP) was implemented by the Western Pacific Regional Fishery Management Council (Council) for the bottom fish and seamount groundfish fisheries of the western Pacific region, which geographically includes Hawaii, American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands. The FMP was prepared under the guidelines of the Magnuson Fishery Conservation and Management Act of 1976, and with passage of the FMP, a conservation and management program for the region's bottom fisheries was put into place.

The bottom fish FMP stipulates that every year a plan monitoring team, whose members are appointed by the Council, will evaluate the biological and economic conditions prevailing in the fishery and will prepare an annual report summarizing its assessment of the fishery. If conditions warrant, the team is responsible for making suggestions to the Council concerning alternatives for corrective management action.

The work presented here, by examining a variety of biological factors and fishery performance indicators gleaned from a market sampling program, represents a biological contribution to the monitoring team's annual appraisal of the Hawaiian bottom fish fishery. Particular attention is paid to the size structure of key species through methods developed in Ralston and Kawamoto (1985, 1987) and Ralston et al. (1986). This is the second year in which a biological contribution to the team's annual report has been prepared.

METHODS

The data used here were derived from a sampling program designed to monitor the landings of commercial fishermen at a centralized wholesale fish market in Honolulu. The bottom fish passing through this market are a subset of the entire statewide commercial catch. Significant markets also exist on Maui, Hawaii, and Kauai. Moreover, there is a sizable recreational harvest of bottom fish. The catch totals compiled here, therefore, in no way represent meaningful, absolute statistics. The value of sampling the catch at this wholesale market is that it is the most centralized point at which a large volume of landings can be intercepted and data economically collected. Because such a large share of the total statewide catch of bottom fish passes through this wholesale market, trends and patterns in the data collected are believed to be indicative of the fishery as a whole. Absolute estimates of the total commercial landings of Hawaiian bottom fish are presented in Pooley and Kawamoto (1988). Our sample comprises roughly two-thirds of their estimates.

At the marketplace, bottom fish are sold either as individual fish or, more commonly, in lots. A lot is composed of a grouping of conspecific fish from a particular fisherman's catch. Significantly, fish are sorted by size before they are assigned to lots, so that all those within a lot tend to be similarly sized (Ralston et al. 1986). For each lot we recorded the following information: (1) the fish species, (2) the total weight (in pounds) of the lot, (3) the number of fish comprising it, (4) the vessel landing the catch, (5) the location of fishing, (6) the purchaser, (7) the sale price, and (8) the date of the transaction. Previous work has shown that 88-99% of the actual size structure (weights and lengths) can be recovered from these simple lot statistics (Ralston et al. 1986).

Data were recorded for almost all lots of bottom fish sold over the 4 yr spanning 1984-87. The data were entered into a computer file, where each lot represents an observation composed of the eight variables listed above. Various summary statistics were computed using Statistical Analysis System computer routines (SAS 1985a, b, c).

Weight-frequency distributions were compiled and analyzed in detail to estimate various biological and fishery dependent parameters. For each distribution considered, the ascending portion of the curve (including the mode) was used to determine the weight at entry to the fishery (w_c) by averaging the minimum size caught with the modal value. Species were assumed fully vulnerable to the gear in all weight categories greater than, but not equal to, the mode. The descending portion of each weight-frequency distribution (excluding the mode) was transformed to a length-frequency polygon using the length-weight regressions in Loubens (1980), Uchiyama et al. (1983), Brouard and Grandperrin (1984), Ralston (in press), and Sudekum et al. (in prep.). The descending portions of these length-frequency polygons were assumed to be representive of the stock; that is the catch was obtained by a uniformly selective sampling process.

The descending limbs of length-frequency distributions, pooled over 1984-87, were used to estimate the maximum length parameter (L_∞) of the von Bertalanffy growth equation by application of the regression method of Wetherall et al. (1987). The growth coefficient (K) was estimated by using the snapper (Lutjanidae) and grouper (Serranidae, subfamily Epinephelinae) growth performance equation provided by Manooch (1987). Natural mortality rates (M) were estimated from the equation provided in Ralston (1987), based on his study of snappers and groupers. Total mortality rates (Z) were estimated from the descending limbs of length-frequency distributions by using the Wetherall regression method (Wetherall et al. 1987), as well as with the the length converted catch curve method of Pauly (1982). There were no obvious systematic differences between the two estimates (Fig. 1), so they were averaged for a final estimate. Fishing mortality rates (F) were determined by subtraction ($F = Z - M$), and ages at entry to the fishery (t_c) were calculated from w_c, the length-weight regression, and the von Bertalanffy growth parameters. Maximum weight parameters (W_∞) were estimated from values of L_∞ and the appropriate length-weight regression.

Yield-per-recruit analyses (Beverton and Holt 1957) were conducted by using the various parameters estimated from size structure (W_∞, K, M, F, t_c). All species were assumed to recruit to the fishery after 1 yr of growth ($t_r = 1.0$), growth was assumed isometric, and the upper bound of the yield equation integral was assumed infinite. The status of the fishery was assessed by determining whether or not, with the most recent year's data, the fishery lay above or below the eumetric fishing line, i.e., the locus of points producing optimal yields per recruit for fixed values of fishing mortality or effort.

RESULTS

The data presented in Table 1 illustrate that the catch of bottom fish available to our market sampling program has generally increased since 1984. The number of sales transactions increased every year, rising 83% in 3 yr. Although the total weight of bottom fish that we intercepted increased each year from 1984 to 1986, in 1987 the weight actually declined from 593.6 metric tons (t) in 1986 to 588.3 t. This only amounts to a 1% decline, however, beyond the limits of statistical certainty of our data. Moreover, this decline was due to a falloff in quantities of imported bottom fish, rather than a diminishing harvest from the Hawaiian fishery (see below). For example, sampled imports from Fiji fell by more than 40 t in 1986-87. However, aside from the anomalous behavior of import landings, which are known from other data sources to have actually increased in 1987 (Pooley and Kawamoto 1988), we believe our sampling location has played a consistent role in the Hawaiian bottom fish market during 1984-87.

A diverse variety of fishes from throughout Oceania are marketed as bottom fish (Table 2). The principal species are snappers (Lutjanidae), groupers (Serranidae), and jacks (Carangidae). Members of the snapper genus *Pristipomoides* are particularly numerous (eight species).

The species composition of bottom fish taken in the Hawaiian fishery is more narrow (Table 3). There are 12 main species, including 8 snappers, 1 grouper, 2 jacks, and the scorpionfish, *Pontinus macrocephala*. Note that opakapaka is the mainstay of the fishery, accounting for 36% of the sampled catch in 1987. The next most important species are onaga, hapuupuu, and butaguchi, each comprising about 15-16% by weight of the combined catch. Note also that during the 1984-87 period the total of samples from Hawaii increased substantially each year, as well as individually from the main Hawaiian Islands (MHI) and the Northwestern Hawaiian Islands (NWHI). For comparative purposes, our sampling suggests that landings from the NWHI are roughly twice as great as those from the MHI. Because of differences in how and where fish from these two regions are marketed, however, the total harvest of bottom fish in the MHI is believed to be almost equivalent to that of the NWHI (Pooley and Kawamoto 1988).

Ralston and Kawamoto (1987) estimated maximum sustainable yield (MSY) for the MHI and NWHI multispecies bottom fisheries; i.e., 285 and 275 t, respectively. The data presented in Table 3 indicate that, in 1987 and in the MHI, our sampling program intercepted landings equal to 61% of MSY. A similar computation for the NWHI fishery shows that intercepted landings were 36% in excess of MSY. However, because our data account for only a portion of the statewide harvest of bottom fish, it is better to compare MSY with total commercial landings, estimated at 386 and 461 t for the MHI and NWHI, respectively (Pooley and Kawamoto 1988). Thus, after being corrected for landings to other markets, the data indicate that commercial harvest levels in the MHI are actually 36% in excess of MSY and that landings from the NWHI are 68% greater than the projected MSY for that region.

Bottom Fishing Effort and CPUE in the NWHI

Fishing effort (trips) and CPUE (pounds per trip) were calculated for the NWHI fishery in a manner identical to that presented in Ralston and Kawamoto (1987) (Table 4). Results show that the total number of bottom fishing trips to the NWHI in 1987 (f = 134) was less than in 1986 (f = 163). A better measure of fishing effort, however, is the number of "effective" trips, i.e., those trips wherein at least 1,000 lb[1] of bottom fish are landed. Under this constraint fishing effort was observed to decline 15% in 1986-87, going from 139 to 118 trips. These were completed by 26 vessels, compared with only 22 the year before. Thus, in 1987 relative to the preceding year, the effective number of trips per vessel declined from 6.3 to 4.5 despite a net influx of boats to the fishery (+4).

Overall CPUE statistics for each of the 4 yr indicate a general increase in the catch per trip (see Ralston and Kawamoto 1987), going from 4,100 lb/trip in 1984 to 6,200 lb/trip in 1987. These figures are somewhat deceiving though, because a different group of boats fished in the 2 yr. Because of the entry and exit of boats to the fishery every year, comparisons of fleetwide CPUE statistics contain an unnecessary error component.

To alleviate this problem, only those nine fishing vessels that have been in the fishery all 4 yr (vessels J-R) were included in calculations of CPUE statistics. The results (Fig. 2) of tracking the performance of these vessels over 4 yr provide a statistically valid indication of conditions within the fishery. Catch rates of opakapaka reversed a declining trend in 1987, rising for the first time since data collection began. The combined species catch rate of all bottom fish (lower panel) also rose appreciably during 1986-87, continuing the rising trend from previous years.

Geographical Patterns of Fishing in the NWHI

Evidence presented in Ralston and Kawamoto (1987) demonstrated that NWHI fishing activity shifted substantially to the northwest in 1986 compared with 1984-85. This was brought about by a major expansion of fishing effort at Lisianski Island. With the addition of information for 1987, we know that last year Maro Reef played a much larger role in bottom fish harvests than it had previously (Fig. 3). Likewise, there was a small but definite harvest of fish from Salmon Bank and Ladd Seamount for the first time, while Pearl and Hermes Reef accounted for an increasing share of the catch. The overall effect is that fishing effort is apparently being distributed more uniformly throughout the NWHI, with less dominance by any one particular locality. The fishing up of virgin stocks of bottom fish seems to have largely run its course.

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[1]Certain statistics are reported in pounds, which is the industry standard in Hawaii. One pound equals 0.45 kg.

The average distance traveled to the fishing grounds to catch a pound of opakapaka can be calculated from the the data presented in Figure 3. The result (Fig. 4) shows that average travel costs remained stable in 1987 relative to 1986. At this time, vessels are traveling an average of 770 nmi in order to catch opakapaka.

Size Structure Analysis

Of the 12 species listed in Table 3 only 7 are caught in quantities significant enough to warrant detailed size structure analysis: opakapaka, onaga, ehu, uku, hapuupuu, butaguchi, and white ulua. The latter species, although not examined by Ralston and Kawamoto (1987), was included in this year's assessment because of its substantial contribution to landings from the NWHI.

Growth and mortality rates were estimated in all 4 yr for each species from the two major regions of the Hawaiian Islands (i.e., the MHI and the NWHI). Where possible, Beverton and Holt (1957) yield-per-recruit analyses were performed. In addition, a more refined geographic analysis of the weight at entry to the fishery ($\underline{w}_c$), asymptotic length ($\underline{L}_\infty$), and mortality to growth ratio (theta = $\underline{Z}/\underline{K}$) was conducted for the seven principal bottom fish species. In this instance, analyses were conducted for each of the eight geographic zones listed in Table 5. This work was based only on the data from 1986 to 1987 because specific locality information in the data from previous years was lacking.

Results of fitting the Wetherall et al. (1987) regression equation to estimate $\underline{L}_\infty$ from the combined 1984-87 data sets for samples from the MHI and NWHI are presented in Table 6. For each species, there is generally good correspondence between estimates of $\underline{L}_\infty$ derived from the MHI and from NWHI samples. It is evident, however, that $\underline{L}_\infty$ values from the MHI typically were the larger of the two (four of five cases); the only exception to this was onaga. Also included in Table 6 are the Manooch (1987) estimates of growth coefficient ($\underline{K}$) and the Ralston (1987) estimates of natural mortality rate ($\underline{M}$). Note also that no attempt was made to perform size structure analysis on either butaguchi or white ulua because these species are neither lutjanid nor serranid, a requirement for using the Manooch (1987) and Ralston (1987) equations. Lastly, the Wetherall regression was not applied to samples of uku from the NWHI or butaguchi from the MHI because of insignificant landings and small sample size (see also Table 3).

Opakapaka

In 1987, the modal size of MHI opakapaka that we encountered in our samples was 2 lb (Fig. 5 upper panel). The descending limb of the length-frequency curve for that year (lower panel) was very similar to the patterns of 1985-86. The resulting estimates of weight at entry ($\underline{w}_c$), length at entry ($\underline{l}_c$), age at entry ($\underline{t}_c$), and fishing mortality ($\underline{F}$) are presented in Table 7 for all the years in which we have data (1984-87). Lastly, the estimated positions of the MHI opakapaka fishery on the Beverton and

Holt (1957) yield-per-recruit surface for each year from 1984 to 1987 are presented in Figure 6.

These results show that the MHI fishery for opakapaka lies slightly below the eumetric fishing line, indicating a marginally growth-overfished condition. If levels of fishing mortality increase any further, then yield per recruit will fall. Only in association with an increase in the age at entry would increases in fishing effort be warranted. At present, the size at entry to the MHI opakapaka fishery is substantially immature (Ralston 1981; Kikkawa 1984).

The situation is very much different in the NWHI. For the fourth year in a row, the modal size of opakapaka landed from this region remained large (9 lb) (Fig. 7). Size at entry to the fishery (Table 7) was also relatively large. Consequently, there is no evidence that the fishery is in any danger of growth-overfishing, inasmuch as all points lie well above the eumetric line (Fig. 8).

A more detailed look at geographical patterns in the most critical opakapaka fishery statistics (Fig. 9) reveals that weight at entry to the fishery increases abruptly as one progresses into the NWHI (zones 4-8) from the MHI (zones 1-3). More ominous is the indication that weight at entry may have fallen precipitously from 1986 to 1987 in zones 4 and 5 (Middle Bank to Gardner Pinnacles). No latitudinal trend is apparent, however, with respect to values of asymptotic length ($\underline{L}_\infty$). Likewise, $\underline{Z}/\underline{K}$ ratios from the NWHI display little coherence, although exactly the opposite is true for the MHI. The similarity of 1986 and 1987 estimates of $\underline{Z}/\underline{K}$ from MHI zones lends credence to the analysis, suggesting that opakapaka stocks from Hawaii to Oahu are exposed to a substantially greater fishing mortality than those around Kauai and Niihau (zone 3).

Onaga

The pattern evidenced by onaga is similar to that of opakapaka, except that levels of fishing mortality in the MHI are much lower. The modal size of onaga caught in the MHI (Fig. 10 upper panel) is very small, resulting in a relatively small size and young age at entry to the fishery (Table 7 and Fig. 11). Compensating for this to some extent, however, are very low estimates of fishing mortality, placing the fishery slightly above the eumetric fishing line. Like opakapaka, the size of onaga at entry to the MHI fishery is much less than the size at which maturity is reached (Everson et al. in prep.).

In the NWHI, however, the modal size of onaga remains large (Fig. 12 upper panel), although $\underline{l}_c$ did drop by almost 10 cm in 1987 (Table 7 and lower panel of Fig. 12). Still, the corresponding estimates of fishing mortality and age at entry indicate that in the NWHI the fishery for onaga is in no danger at present (Fig. 13).

Examination of vital statistics by zone (Fig. 14) reveals that, like opakapaka, the weight of onaga at entry to the fishery increases abruptly in the NWHI and that, compared with 1986, somewhat smaller fish were caught in 1987 in zones 4 and 5. Similarly, like opakapaka, no particular trend is obvious in the estimates of asymptotic length. Mortality to growth ratios ($\underline{Z}/\underline{K}$) by zone seem to consistently indicate a higher level of fishing mortality from Hawaii to Lanai (zone 1). In the NWHI (zones 4-8), the pattern is erratic and unstable.

Ehu

Of all the species examined, the analysis presented here suggests that the ehu is the most severely stressed. In 1987, the modal size of the MHI harvest of this species was 1 lb (Fig. 15 upper panel). Note that a substantial number of fish were assigned a rounded weight of 0.0 lb, i.e., their true weight must have been 0.0-0.5 lb. It is not surprising that the size at entry to the MHI fishery is, like opakapaka and onaga, much less than the size at maturity (Table 7; Everson 1984). Moreover, the descending limbs of the length-frequency polygons for 1984-87 (Fig. 15 lower panel) all demonstrate substantial curvature, indicative of high fishing mortality. These results show (Fig. 16) that the MHI ehu fishery is substantially growth-overfished. Further increases in fishing mortality or decreases in $\underline{t}_c$ will have a negative impact on yields. In fact, the extent of growth-overfishing is so great as to raise concern over the likelihood of recruitment-overfishing.

The situation is very different for NWHI stocks of ehu. There, the modal size of the 1987 catch was 3 lb (Fig. 17 upper panel). The size at entry to the fishery (Table 7) is believed to be equal to, more or less, the size at first reproduction (Everson 1984). The level of curvature in the descending limbs of the length-frequency polygons for 1984-87 is nowhere near as great as the MHI (Fig. 17 lower panel), and the yield-per-recruit analysis (Fig. 18) indicates that the NWHI fishery lies above the eumetric fishing line at present. Thus, there is no cause for alarm, although, of the three NWHI species analyzed thus far, ehu show greater evidence of the effects of fishing (Figs. 8, 13, and 18).

Likewise, geographical variations in ehu vital statistics show clear and definitive patterns among weight at entry, asymptotic length, and mortality to growth ratios (Fig. 19). Weight at entry statistics show the now consistent trend of weights increasing markedly as one progresses up the Hawaiian Archipelago. A declining trend also appears through zones 1-8 in estimates of asymptotic length. Most important, mortality to growth ratios show a coherent pattern of decline as one moves from the southeast to the northwest.

Uku

The MHI fishery for uku also shows evidence of growth-overfishing, but in this case, the analysis suggests that age at entry is not excessively low. For example, in 1987, the modal size of MHI uku was 6 lb (Fig. 20 upper panel). Rather, the suggestion of overfishing comes instead from the significant curvature of the descending limbs of the length-frequency polygons for the years 1984-87 (Fig. 20 lower panel). Taken together, these results show that the fishery presently lies below the eumetric fishing line (Table 7 and Fig. 21). One encouraging note is that the estimate of fishing mortality for 1987 is substantially less than in previous years.

Because there is no significant fishery for uku in the NWHI (Table 3) the analysis of vital statistics by zone includes only data from zones 1-3 (Fig. 22). Given such a narrow spatial range in which to establish geographical variation, perhaps it is not surprising that little pattern is evident in the estimates of weight at entry, asymptotic length, and mortality to growth ratios.

Hapuupuu

The evidence we have gathered suggests that the fishery for hapuupuu in the MHI is close to an optimal state of utilization, at least from the perspective of yield per recruit. In 1987, the modal size of this grouper was 8 lb (Fig. 23 upper panel). The amount of curvature in the length-frequency polygon data (Fig. 23 lower panel) is not excessive. Together these results support the view that little could be done to improve the MHI fishery for hapuupuu (Table 7 and Fig. 24). The fishery currently is on the eumetric line and is producing about 0.70 kg/recruit.

Stocks of hapuupuu from the NWHI demonstrate a very interesting reversal of trend from the results presented thus far. For all other species the size at entry to the fishery is smaller in the MHI than the NWHI (Figs. 9, 14, 19, and section on white ulua). Not so with hapuupuu. The modal size of fish from the NWHI in 1987 was 4 lb (Fig. 25 upper panel), and the sizes and ages at entry to the fishery are consistently smaller for fish from this region when compared with the MHI (Table 7). Still, the amount of curvature in the descending limbs of the length-frequency polygons for NWHI hapuupuu is low (Fig. 25 lower panel), and the yield-per-recruit analysis (Fig. 26) suggests that the fishing mortality rate in this fishery could be increased.

The analysis of hapuupuu vital statistics by geographical zone (Fig. 27) also illustrates the declining trend in weight at entry with distance up the Hawaiian Archipelago, at least as far as zone 7 (Lisianski Island). A similar trend is evident in estimates of asymptotic length and mortality to growth ratios. The overall consistency of these results support the yield-per-recruit analyses presented in Figures 24 and 26.

Butaguchi

The butaguchi is a carangid and cannot be analyzed by the methods utilized thus far. In particular, the use of the Manooch (1987) and Ralston (1987) equations to estimate the von Bertalanffy growth coefficient ($\underline{K}$) and natural mortality rate ($\underline{M}$), respectively, is not appropriate. This restriction precludes yield-per-recuit analysis. Moreover, no significant fishery exists for this species in the MHI (Table 7), so no attempt has been made to describe the situation in this region. Nonetheless, the NWHI fishery for butaguchi is substantial, where the modal size of fish landed in 1987 was 14 lb (Fig. 28 upper panel). This actually represents an increase in the length at entry to the fishery in 1987 when compared with 1986 (Fig. 28 lower panel). Application of the Wetherall et al. (1987) regression method to the descending limbs of length-frequency distributions of butaguchi stocks sampled from zones 4-8 (Fig. 29) shows little coherent structure. From these results, there is little evidence of overfishing on butaguchi stocks, especially because weight at entry is relatively large (upper panel in Fig. 29).

White Ulua

Although the white ulua was not included in the previous assessment of the Hawaiian bottom fishery (Ralston and Kawamoto 1987), it is an important species, especially in the NWHI (Table 3), and is examined here for the first time.

Ralston and Kawamoto (1987) provided individual weight-frequency distributions for opakapaka, onaga, ehu, uku, hapuupuu, and butaguchi harvested in the MHI and NWHI for the years 1984-86. These have not been included here. Equivalent data are presented for the white ulua in Figure 30, which indicates that much smaller fish are landed from the MHI than from the NWHI. The modal size of white ulua landed from the MHI in 1987 was 4 lb (Fig. 31 upper panel). A very large harvest of juvenile white ulua characterizes the MHI (Fig. 31 lower panel; Sudekum et al. in prep.). Such small individuals are commonly known as papio.

The exact opposite is true of the NWHI where the modal size of the 1987 landings was 36 lb (Fig. 32 upper panel). The results of applying the Wetherall et al. (1987) regression method to estimate vital statistics by geographical zone (Fig. 33) confirms the tremendous difference in weights at entry to the fisheries in the MHI and NWHI (upper panel). The extent to which small juvenile fish are harvested in the MHI is adequate reason to be concerned about the prevalence of recruitment-overfishing in this area.

Incidental Species

Up to this point 7 of the 12 species listed in Table 3 have been examined in some detail. Of the remaining five, size structure over the 1984-87 period was summarized for kalekale, gindai, hogo, and lehi. A similar summary was not possible for taape, because, in our sampling program for this species, the number of individuals comprising individual market samples was frequently unavailable for recording.

Results show there have been no major changes in the size-structure of kalekale, gindai, hogo, or lehi over the 1984-87 period (Figs. 34-37). This conclusion is true for both the MHI and the NWHI. However, like most species examined so far, the weight at entry and mean size of fish caught in the MHI is typically less than in the NWHI. This is especially true of kalekale and gindai. Note that lehi is not caught in the NWHI (Table 3) so no comparison is possible.

DISCUSSION

In the last assessment of the Hawaiian bottom fishery (Ralston and Kawamoto 1987), an explicit discussion of key assumptions was included. A detailed reiteration of these will, therefore, not be attempted here. Rather a simple listing of the principal assumptions invoked in the preceding size structure analyses follows: (1) the size structure of bottom fish catches is accurately represented by the methods of Ralston et al. (1986), (2) descending limbs of catch length-frequency polygons are representative of stock size structure, (3) snapper and grouper growth coefficients and natural mortality rates are reasonably estimated by the comparative method (e.g., Manooch (1987) and Ralston (1987)), (4) recruitment to the exploitable phase is independent of stock size, (5) it is desirable to optimize the yield in biomass from a fishery, and (6) equilibrium conditions prevail.

Given these assumptions, with their associated caveats, we draw several conclusions concerning the status of bottom fish stocks in the Hawaiian Islands. The conclusions themselves are based not so much on any particular parameter estimates produced from the analyses we conducted, but rather on the patterns and broad generalizations that emerged after having examined the many combinations of species, years, and regions in their totality. It would, in fact, be unwise to place too much emphasis on any single fact or figure reported herein, simply because of the many assumptions we have made.

In the NWHI, there is little to suggest that the fishery is stressed. Both catches and CPUE statistics are increasing in the conjunction with declining fishing effort. Likewise, size structure analysis failed to reveal any fishery for a NWHI species lying below the eumetric fishing line. The only potentially alarming NWHI fishery statistic that we encountered is that landings currently are 68% in excess of our best estimate of MSY. For two reasons, however, this "warning sign" must be viewed with caution. First, given the slow growth of snapper and grouper species (Manooch 1987), the fishery likely continues in a state of disequilibrium (Ralston and Kawamoto 1987). This condition renders ambiguous our estimates of MSY. Second, even our current understanding of equilibrium productivity is not well grounded.[2] For these reasons, we believe that no immediate action is warranted to further manage NWHI stocks of bottom fish.

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[2]Memorandum dated 27 March 1986 from S. Ralston (Southwest Fisheries Service Honolulu Laboratory, National Marine Fisheries Service, NOAA, 2570 Dole Street, Honolulu, HI 96822-2396) to members of the bottom fish monitoring team summarizes information concerning the productivity of bottom fish stocks.

The situation in the MHI is somewhat different. Total landings (Table 3) show an increasing trend, suggestive of what likely represents increases in bottom fishing effort. Estimates of statewide commercial catch (Pooley and Kawamoto 1988) exceed our best estimate of MSY. Likewise, yield-per-recruit analyses (Figs. 6, 11, 16, 21, and 24) show a chronic pattern of harvesting undersized fish. This is true especially of opakapaka, onaga, ehu, and white ulua (see also Figs. 9, 14, 19, and 33). In 1987, these four species accounted for almost 80% of the MHI bottom fishery by weight, and in combination, they likely represent an even greater share of ex-vessel revenues.

Polovina (1987) suggests that if snapper and grouper stocks are harvested in such a way that the length at entry to the fishery (l_c) is less than the length at first maturity (l_m), greater restraint is needed to avoid recruitment overfishing. Indeed, for the five species of Hawaiian bottom fish whose reproductive biology has been examined (Ralston 1981; Everson 1984; Kikkawa 1984; Everson et al. in prep.; Sudekum et al. in prep.), four are characterized by $l_c < l_m$, i.e., opakapaka, onaga, ehu, and white ulua (Fig. 38). The situation is particularly egregious for onaga. Recent work by Everson et al. (in prep.) shows that this species does not reach reproductive maturity until it is 66 cm fork length (FL), whereas in 1987 MHI onaga entered the fishery at a size of 30 cm FL (Table 7). With such a broad window of exploitation on immatures (6.5 yr), were it not for the relatively low level of fishing mortality, this species could likely face immediate recruitment collapse.

One of the most effective means of reducing the harvest of undersized immature fish is to impose restrictions that will raise the age at entry to the fishery (t_c). Management has often accomplished this through enactment of gear restrictions on the capture of fish. Such an approach would not seem fruitful here (Council 1986). Rather, we suggest that limitations on the commercial sale of undersized fish be given serious consideration. In this regard, the estimation of the optimum legal size for each of the bottom fish species has not been attempted. Moreover, the establishment of recreational "bag limits" (e.g., allowing possession of some number of undersized fish) would serve to protect the interests of sportfishing enthusiasts and would ensure their continued participation in the fishery.

There is ample evidence to show that experienced commercial fishermen could avoid capturing undersized fish, were they motivated to do so. Several studies have shown that fishing with larger hooks greatly reduces the capture of small fish (Ralston 1982; Ralston and Shiota in prep.). Likewise, juveniles are typically found in large concentrations close to the bottom. A high catch rate of juveniles can be much reduced or eliminated entirely by either fishing farther off the bottom (e.g., onaga or opakapaka) or by moving the vessel away from the nursery area. The latter strategy is possible because bottom fish typically follow Heincke's Law, wherein large old fish tend to be found in deeper water than the smaller and younger fish.

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Without the helpful cooperation of all the people at the wholesale fish market and the United Fishing Agency, this study would not have been possible. Also, mahalo to all the skippers and owners of fishing vessels that graciously provided information about their fishing activities, and to the wholesalers who attend the auction every day. On occasion, Joanne Ho of the Hawaii Division of Aquatic Resources helped in the collection of data, for which we are most appreciative.

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Table 1.--Number of bottom fish transactions (N) and weight (in metric tons) of catch based on our market sampling program in Honolulu, 1984-87.

Year	N	Total weight
1984	22,461	418.2
1985	34,612	529.8
1986	39,808	593.6
1987	41,136	588.3

Table 2.--Species composition of bottom fish landings at the wholesale market from 1984 to 1987.

Species	Total landings (kg)			
	1984	1985	1986	1987
Unidentified lutjanid	47.6	501.7	1.4	26.8
Aphareus furca	101.2	112.0	29.9	4.8
A. rutilans	3,078.1	9,452.3	6,322.0	5,095.3
Aprion virescens	34,902.7	9,376.1	24,563.0	11,873.6
Etelis carbunculus	11,389.1	28,930.2	58,627.2	33,744.0
E. coruscans	42,460.8	91,701.9	114,712.4	91,034.0
E. radiosus	9.5	384.4	1,019.0	117.7
Lutjanus fulvus	378.3	324.5	585.1	614.2
L. kasmira	7,874.0	14,843.5	7,200.4	10,944.6
Paracaesio spp.	--	206.8	124.5	--
P. kusakarii	14.5	217.5	1,059.6	296.0
P. stonei	--	--	--	117.0
Pristipomoides auricilla	146.3	3,063.4	263.1	59.4
P. argyrogrammicus	--	8.6	4.5	0.2
P. filamentosus	188,949.0	176,369.2	160,265.8	196,473.5
P. flavipinnis	367.9	425.0	465.2	172.1
P. multidens	115.9	916.3	1,807.8	93.2
P. sieboldii	5,958.5	9,890.9	8,392.9	9,164.2
P. typus	--	8.2	19.1	--
P. zonatus	2,256.4	4,090.8	4,684.5	3,761.5
Randallichthys sp.	--	--	--	7.0
Unidentified serranid	40.4	87.5	413.0	109.7
Caprodon schlegeli	13.4	3.6	11.1	29.5
C. unicolor	--	--	854.6	14.3
Cephalopholis argus	72.1	282.1	170.1	656.4
Epinephelus quernus	54,067.4	71,938.0	90,485.8	86,886.1
Plectropoma sp.	--	383.1	--	--
Variola louti	1.1	2.5	--	--
Unidentified carangid	57.8	6.6	7,420.2	7,001.5
Alectis spp.	206.2	80.3	317.1	845.3
Carangoides equula	28.6	16.3	47.9	239.3
C. orthogrammus	3,326.0	2,817.8	5,703.5	6,278.0
Caranx ignobilis	21,390.7	39,080.6	20,254.2	24,928.6
C. helvolus	765.2	634.6	1,144.2	1,250.1
C. lugubris	1,062.1	890.2	970.7	725.5
C. melampygus	6,306.4	2,867.6	6,091.6	6,035.6
C. sexfasciatus	256.5	118.6	223.9	156.7
Gnathanodon speciosus	5.4	33.8	24.5	46.5
Pseudocaranx dentex	31,832.8	58,397.7	66,718.0	81,987.0
Seriola spp.	9.3	278.1	955.7	1,689.2
Erythrocles sp.	86.9	71.9	64.9	155.1
Pontinus macrocephala	643.2	1,018.8	1,534.5	21.5

Table 3.--Landings of principal bottom fish species from the main Hawaiian Islands (MHI) and Northwestern Hawaiian Islands (NWHI) sampled at the Honolulu wholesale market in 1984-87.

Species	Region	Catch (metric tons) 1984	1985	1986	1987
Aphareus rutilans (lehi)	MHI	2.7	3.7	2.4	4.3
	NWHI	0.1	0.0	0.0	0.0
Aprion virescens (uku)	MHI	31.1	8.1	20.9	10.4
	NWHI	3.4	0.7	3.1	1.3
Etelis carbunculus (ehu)	MHI	6.5	12.9	11.9	12.6
	NWHI	2.2	9.3	12.5	15.0
Etelis coruscans (onaga)	MHI	36.7	64.4	58.1	60.3
	NWHI	3.1	23.4	43.6	28.9
Lutjanus kasmira (taape)	MHI	7.8	14.6	7.2	10.9
	NWHI	0.1	0.2	0.0	0.0
Pristipomoides filamentosus (opakapaka)	MHI	37.5	30.9	36.5	57.6
	NWHI	143.4	140.5	122.6	137.8
Pristipomoides sieboldii (kalekale)	MHI	4.4	6.9	5.6	7.6
	NWHI	1.3	2.9	2.8	1.6
Pristipomoides zonatus (gindai)	MHI	0.6	0.8	0.9	0.5
	NWHI	1.3	2.7	3.4	3.2
Epinephelus quernus (hapuupuu)	MHI	6.7	3.4	3.6	3.8
	NWHI	46.1	66.8	86.7	83.1
Caranx ignobilis (white ulua)	MHI	8.7	7.2	6.9	3.8
	NWHI	12.0	27.7	13.4	21.1
Pseudocaranx dentex (butaguchi)	MHI	0.8	0.4	0.6	1.2
	NWHI	29.5	56.2	66.1	80.8
Pontinus macrocephala (hogo)	MHI	0.4	0.9	1.0	1.1
	NWHI	0.2	0.1	0.5	0.7
All 12 species	MHI	144.0	154.2	155.7	174.3
	NWHI	242.7	330.4	354.7	373.5
Total		386.7	484.6	510.5	547.9

Table 4.--Effective effort (number of 1,000-lb trips) and catch per unit effort (CPUE) (pounds of bottom fish per trip) for the Northwestern Hawaiian Islands bottom fish fishery from 1984 to 1987.

	1984		1985		1986		1987	
Vessel	Trips	CPUE	Trips	CPUE	Trips	CPUE	Trips	CPUE
A	2	6,105	--	--	--	--	--	--
B	1	1,044	--	--	--	--	--	--
C	7	2,650	--	--	--	--	--	--
D	10	10,584	--	--	--	--	1	--
E	2	2,744	--	--	--	--	1	2,299
F	4	1,314	1	2,058	--	--	--	--
G	4	3,392	3	4,099	--	--	--	--
H	8	4,031	6	3,201	--	--	--	--
I	3	1,786	4	1,600	1	1,207	--	--
J	5	3,970	11	4,267	8	4,337	11	5,613
K	12	8,351	13	8,194	11	6,141	4	7,178
L	12	4,691	5	3,520	2	3,407	3	4,317
M	6	5,106	10	5,595	8	3,255	7	4,760
N	3	4,461	3	2,963	4	4,998	5	5,182
O	10	3,058	15	4,241	11	4,037	11	5,759
P	5	3,684	4	3,295	13	4,698	3	7,469
Q	4	3,152	16	5,811	15	5,523	16	9,379
R	9	3,613	5	3,160	8	6,254	6	4,998
S	--	--	4	6,926	5	7,306	3	9,769
T	--	--	1	3,338	9	8,339	6	13,564
U	--	--	1	3,984	3	1,152	2	5,295
V	--	--	1	2,339	2	1,196	3	6,868
W	--	--	11	8,805	11	11,091	11	12,035
X	--	--	13	7,278	7	6,086	2	6,712
Y	--	--	6	1,605	6	1,877	--	--
Z	--	--	1	5,527	--	--	1	4,545
AA	--	--	--	--	3	11,140	3	14,336
BB	--	--	--	--	1	1,152	2	3,612
CC	--	--	--	--	3	3,705	2	5,914
DD	--	--	--	--	7	1,498	2	1,629
EE	--	--	--	--	1	6,476	--	--
FF	--	--	--	--	--	--	3	3,360
GG	--	--	--	--	--	--	3	1,712
HH	--	--	--	--	--	--	3	2,961
II	--	--	--	--	--	--	4	5,535
Total	107	--	134	--	139	--	118	--

Table 5.--Definition of zone codes used in detailed geographical analyses of stock condition.

Zone	Islands and banks included
1	Hawaii, Maui, Kahoolawe, and Lanai.
2	Molokai; Oahu.
3	Kauai; Niihau.
4	Middle Bank, Nihoa, Twin Banks, and Necker Island.
5	French Frigate Shoals, Brooks Banks, St. Rogatien, and Gardner Pinnacles.
6	Raita Bank, Maro Reef, Laysan Island, and Northampton Seamount.
7	Pioneer Bank; Lisianski Island.
8	Pearl and Hermes Reef, Salmon Bank, and Ladd Seamount.

Table 6.--Summary of growth and natural mortality parameter estimates for the seven major bottom fish species studied from the main Hawaiian Islands (MHI) and the Northwestern Hawaiian Islands NWHI).

Species	Region	$\underline{L}_{\infty}$ (cm)	Standard error	$\underline{K}$ (yr^{-1})	$\underline{M}$ (yr^{-1})
Pristipomoides filamentosus	MHI	81.2	0.883	0.153	0.305
(opakapaka)	NWHI	78.1	1.164	0.157	0.313
Etelis coruscans (onaga)	MHI	88.4	0.534	0.144	0.289
	NWHI	92.2	0.955	0.140	0.281
Etelis carbunculus (ehu)	MHI	74.4	1.120	0.162	0.323
	NWHI	68.6	0.986	0.170	0.341
Aprion virescens (uku)	MHI	119.1	4.372	0.119	0.237
	NWHI	--	--	--	--
Epinephelus quernus (hapuupuu)	MHI	119.0	0.662	0.119	0.237
	NWHI	105.5	1.125	0.128	0.257
Pseudocaranx dentex (butaguchi)	MHI	--	--	--	--
	NWHI	97.7	1.986	--	--
Caranx ignobilis (white ulua)	MHI	157.0	3.472	--	--
	NWHI	136.2	2.272	--	--

Table 7.--Summary of fishery parameter estimates for the seven major bottom fish species studied from the main Hawaiian Islands (MHI) and the Northwestern Hawaiian Islands (NWHI) (w_c = weight at entry, l_c = length at entry, t_c = age at entry, and F = fishing mortality.

Species	Region	Parameter	Year 1984	1985	1986	1987
Opakapaka	MHI	w_c (kg)	0.68	0.68	0.45	0.45
		l_c (cm)	33.60	33.60	29.20	29.20
		t_c (yr)	2.85	2.85	2.26	2.26
		F (yr^{-1})	0.10	0.27	0.21	0.19
	NWHI	w_c (kg)	2.27	2.27	2.27	2.49
		l_c (cm)	51.10	51.10	51.10	52.80
		t_c (yr)	6.11	6.11	6.11	6.53
		F (yr^{-1})	0.44	0.24	0.13	0.12
Onaga	MHI	w_c (kg)	0.68	0.45	0.68	0.45
		l_c (cm)	34.40	29.90	34.40	29.90
		t_c (yr)	2.76	2.20	2.76	2.20
		F (yr^{-1})	0.06	0.01	0.01	0.01
	NWHI	w_c (kg)	3.86	2.95	3.40	2.04
		l_c (cm)	62.60	57.10	60.00	50.30
		t_c (yr)	7.44	6.21	6.83	4.96
		F (yr^{-1})	0.10	0.21	0.14	0.01
Ehu	MHI	w_c (kg)	0.23	0.23	0.23	0.23
		l_c (cm)	23.70	23.70	23.70	23.70
		t_c (yr)	1.72	1.72	1.72	1.72
		F (yr^{-1})	0.43	0.52	0.53	0.49
	NWHI	w_c (kg)	0.68	0.91	0.91	0.91
		l_c (cm)	33.90	37.30	37.30	37.30
		t_c (yr)	3.34	3.93	3.93	3.93
		F (yr^{-1})	0.16	0.07	0.13	0.14
Uku	MHI	w_c (kg)	2.27	2.04	2.72	1.59
		l_c (cm)	54.30	52.50	57.60	48.40
		t_c (yr)	4.47	4.24	4.91	3.74
		F (yr^{-1})	0.49	0.45	0.77	0.29
Hapuupuu	MHI	w_c (kg)	1.81	2.27	1.81	1.81
		l_c (cm)	47.00	50.50	47.00	47.00
		t_c (yr)	3.57	3.99	3.57	3.57
		F (yr^{-1})	0.14	0.12	0.12	0.11
	NWHI	w_c (kg)	0.91	0.91	1.36	0.91
		l_c (cm)	37.60	37.60	42.80	37.60
		t_c (yr)	2.77	2.77	3.39	2.77
		F (yr^{-1})	0.01	0.01	0.01	0.01

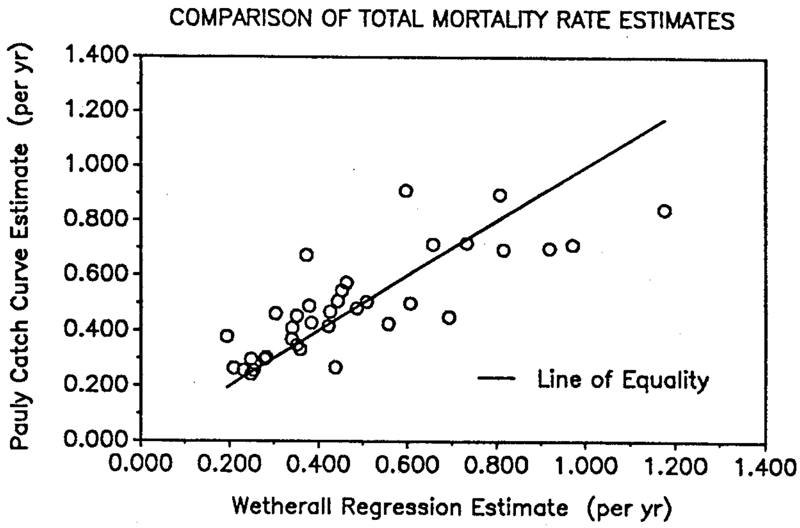


Figure 1.--Scatterplot showing the similarity of total mortality rate estimates obtained by the Wetherall et al. (1987) regression method and the Pauly (1982) length converted catch curve approach.

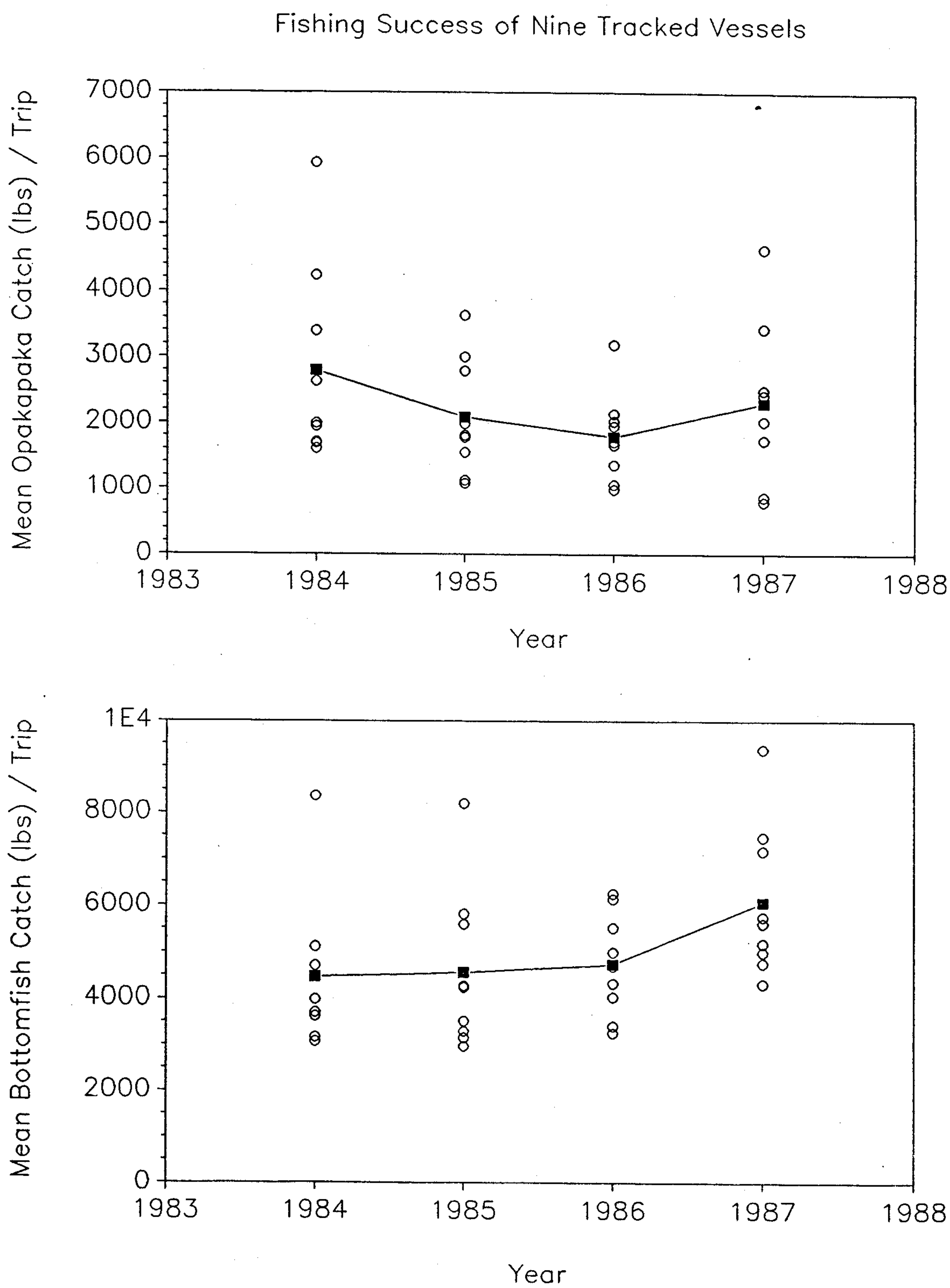
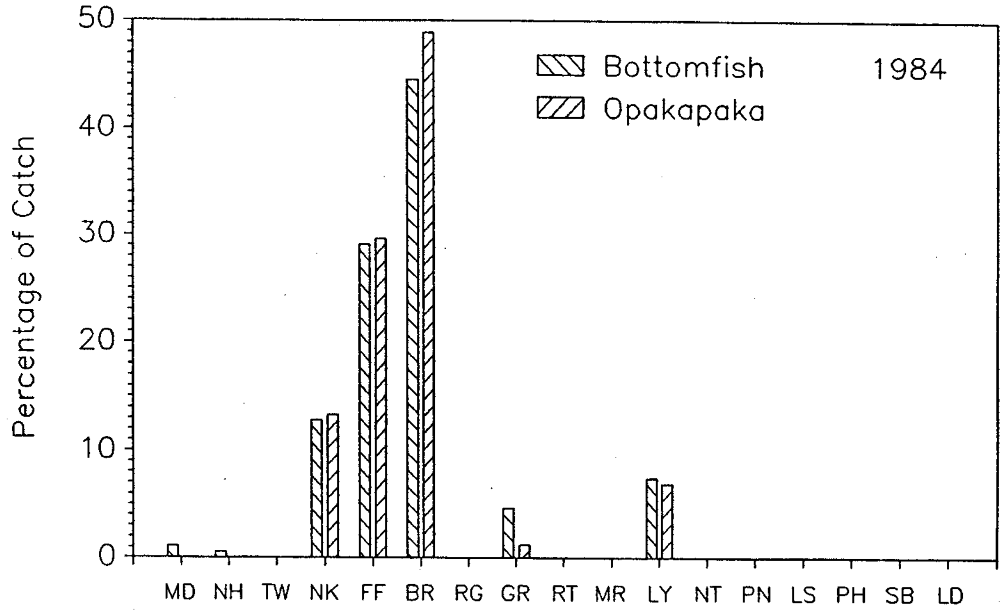


Figure 2.--Catch rate statistics (opakapaka above and bottom fish below) for the nine Northwestern Hawaiian Islands vessels active during the 1984-87 period. Open circles are annual mean catch rates for individual vessels; closed squares are the yearly group means.



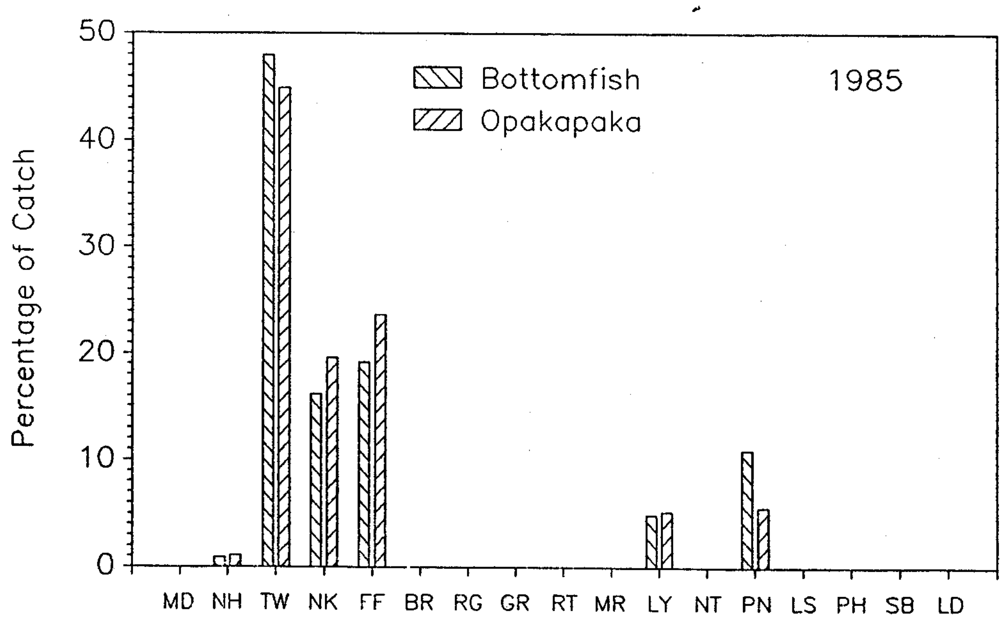
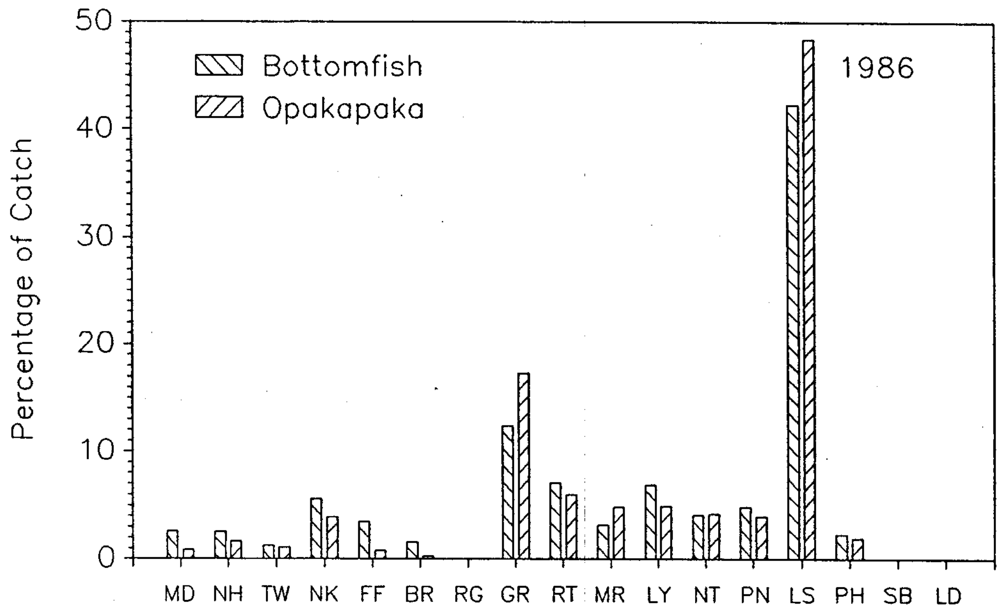


Figure 3.--Locations of bottom fish and opakapaka harvests in the Northwestern Hawaiian Islands, 1984-87: MD = Middle Bank, NH = Nihoa, TW = Twin Banks, NK = Necker Island, FF = French Frigate Shoals, BR = Brooks Banks, RG = St. Rogatien, GR = Gardner Pinnacles, RT = Raita Bank, MR = Maro Reef, LY = Laysan Island, NT = Northampton Seamount, PN = Pioneer Bank, LS = Lisianski Island, PH = Pearl and Hermes Reef, SB = Salmon Bank, and LD = Ladd Seamount.



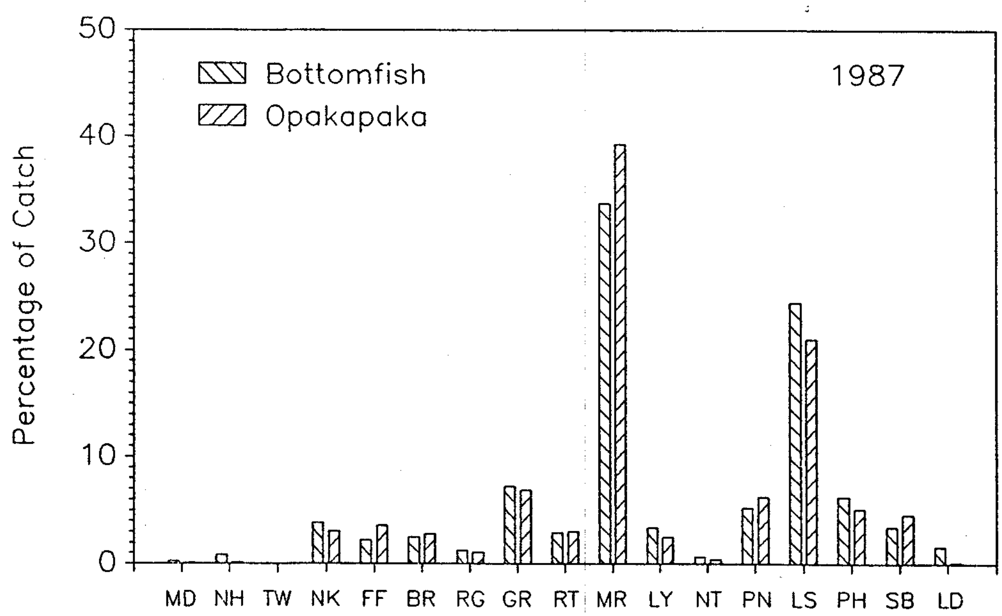


Figure 3.--Continued.

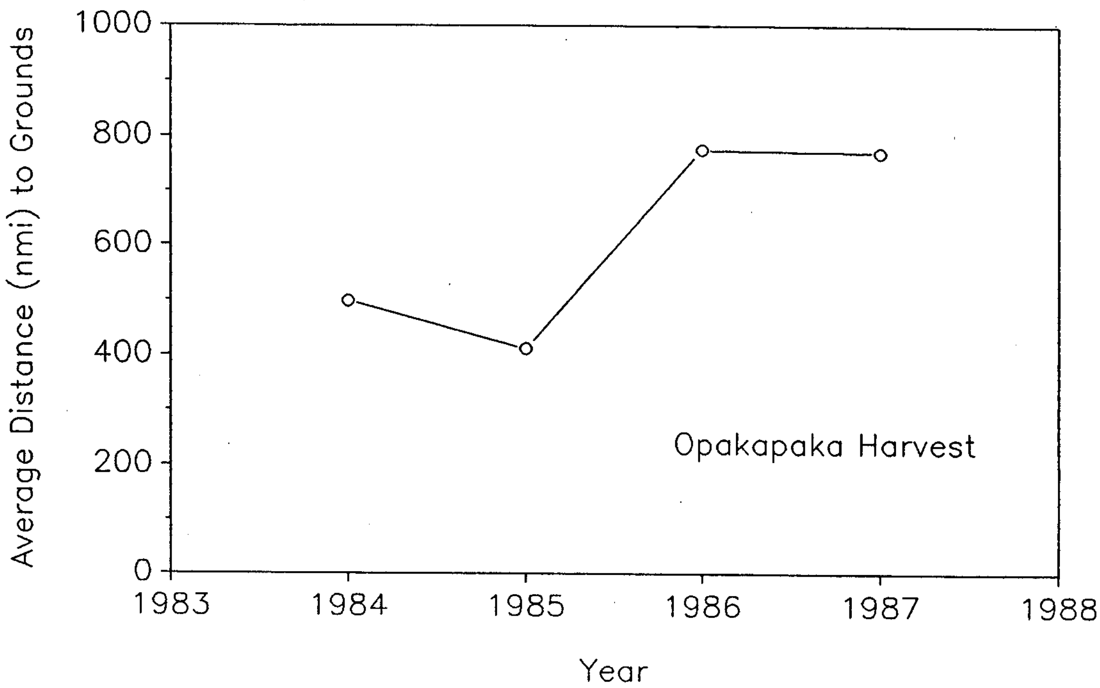


Figure 4.--Traveling distance to obtain an average pound of opakapaka in the Northwestern Hawaiian Islands, 1984-87.

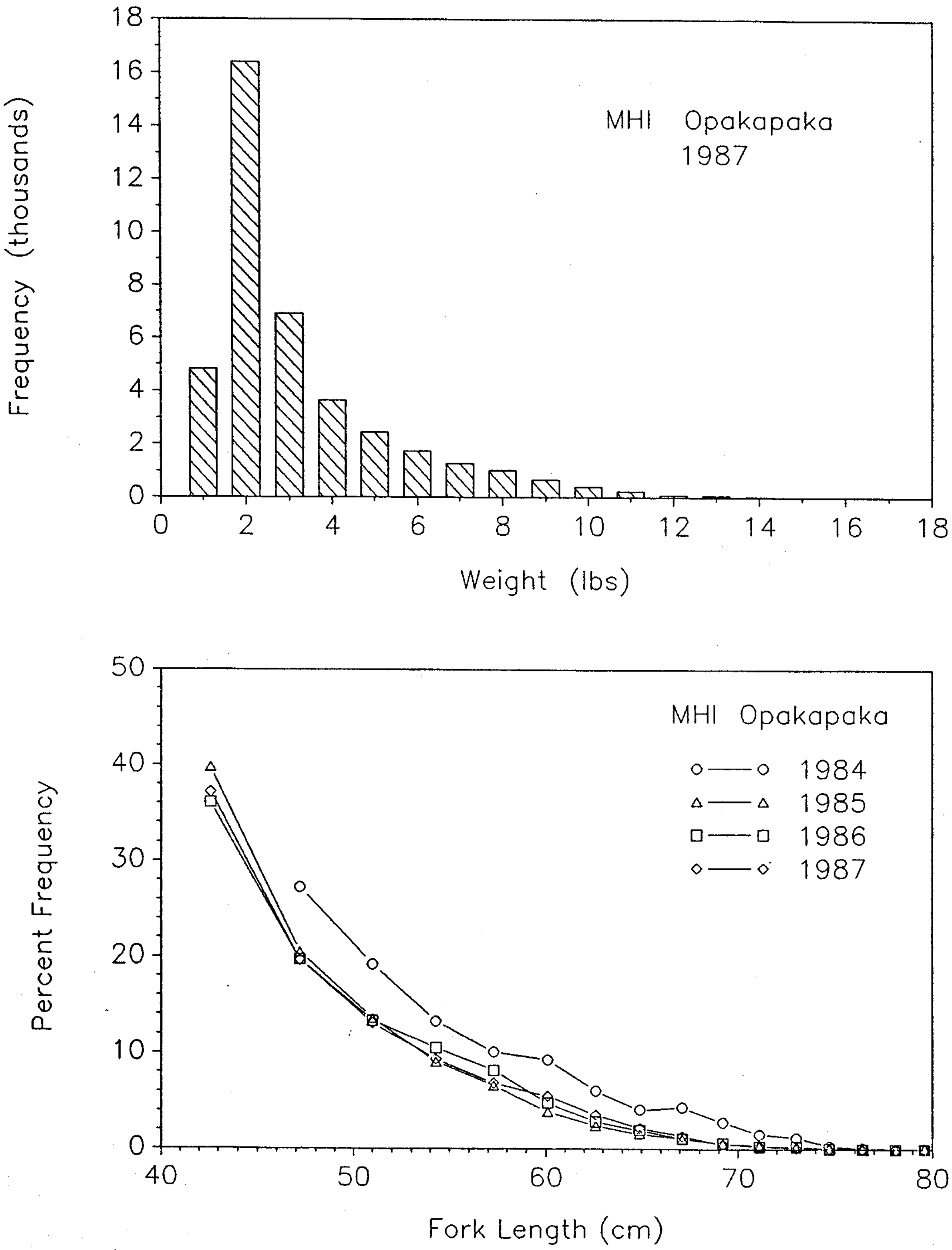


Figure 5.--Weight-frequency distribution of main Hawaiian Islands (MHI) opakapaka based upon 1987 market samples (upper panel) and descending limbs of estimated relative length-frequency distributions for each year from 1984 to 1987 (lower panel).

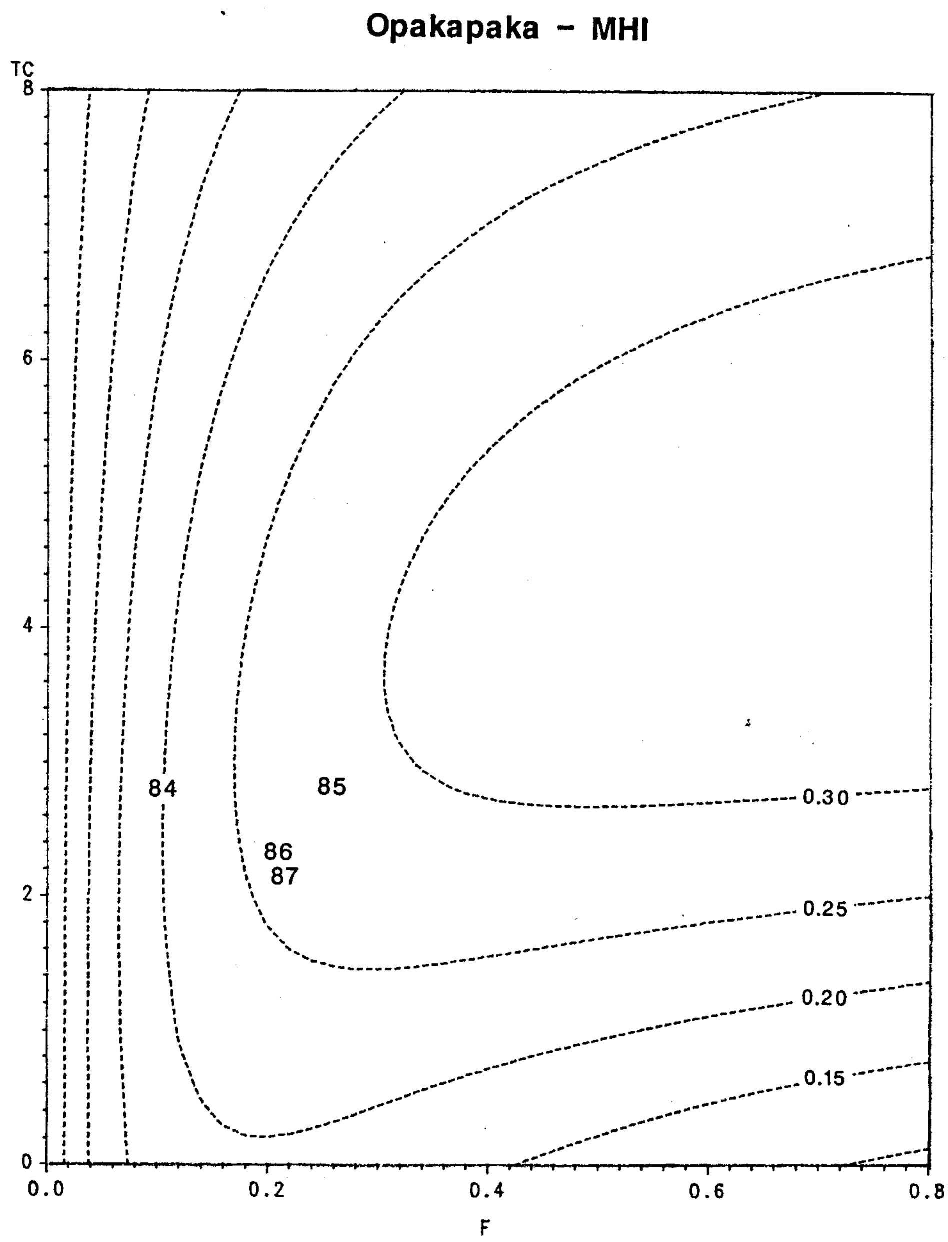


Figure 6.--Yield-per-recruit analysis for main Hawaiian Islands (MHI) opakapaka (1984-87). The unit of fishing mortality ($\underline{F}$) is yr^{-1}, and the unit of age at entry ($\underline{t}_c$) is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (in kilograms). Changes within the fishery are shown on an annual basis.

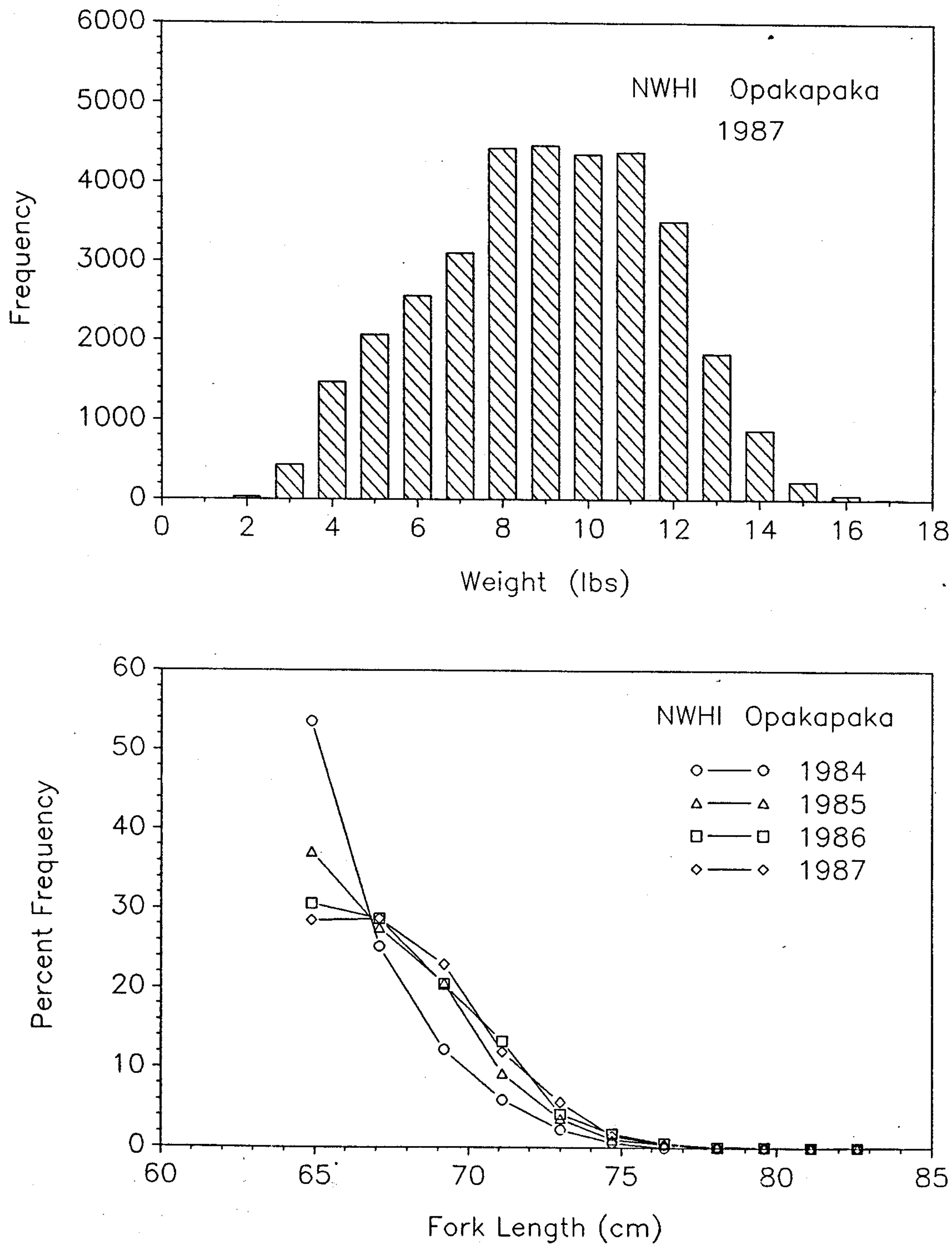


Figure 7.--Weight-frequency distribution of Northwestern Hawaiian Islands (NWHI) opakapaka based upon 1987 market samples (upper panel) and descending limbs of estimated relative length-frequency distributions for each year from 1984 to 1987 (lower panel).

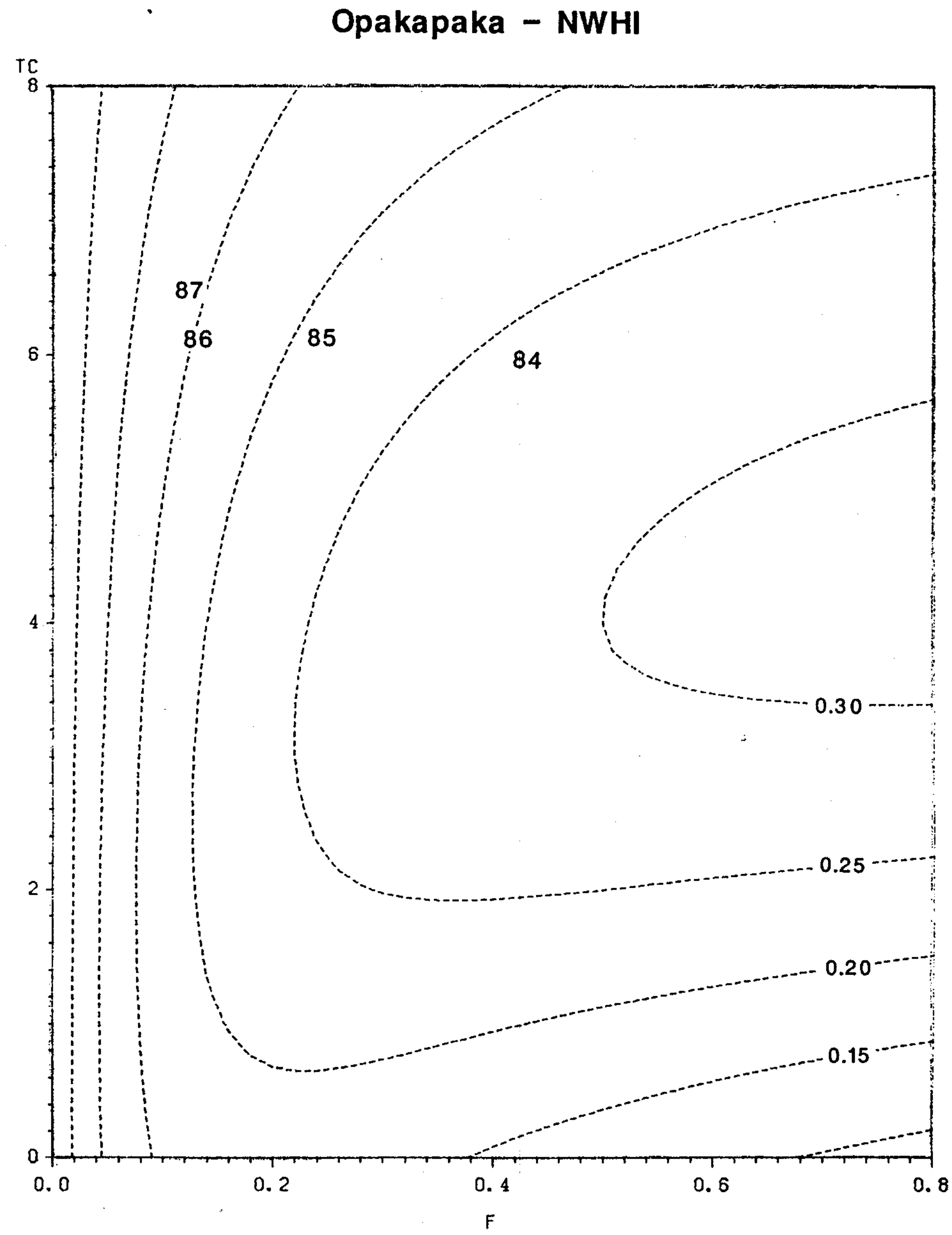


Figure 8.--Yield-per-recruit analysis for Northwestern Hawaiian Islands (NWHI) opakapaka (1984-87). The unit of fishing mortality ($\underline{F}$) is yr^{-1}, and the unit of age at entry ($\underline{t}_c$) is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (in kilograms). Changes within the fishery are shown on an annual basis.

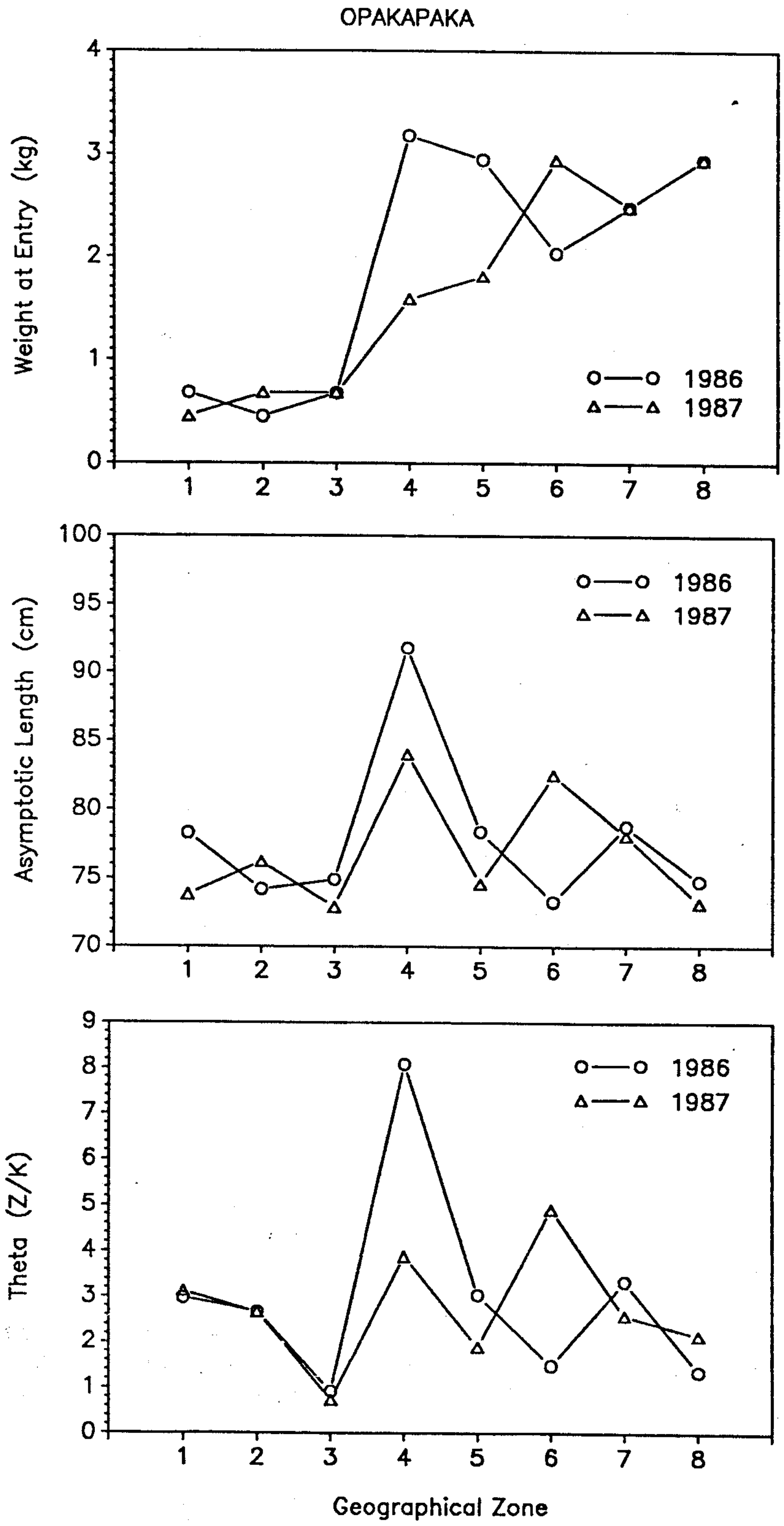


Figure 9.--Relationship of critical opakapaka fishery statistics to geographical zone (see Table 5). Shown are estimates of weight at entry, asymptotic length, and mortality to growth ratio (theta ($\underline{Z}/\underline{K}$)) for the years 1986 and 1987.

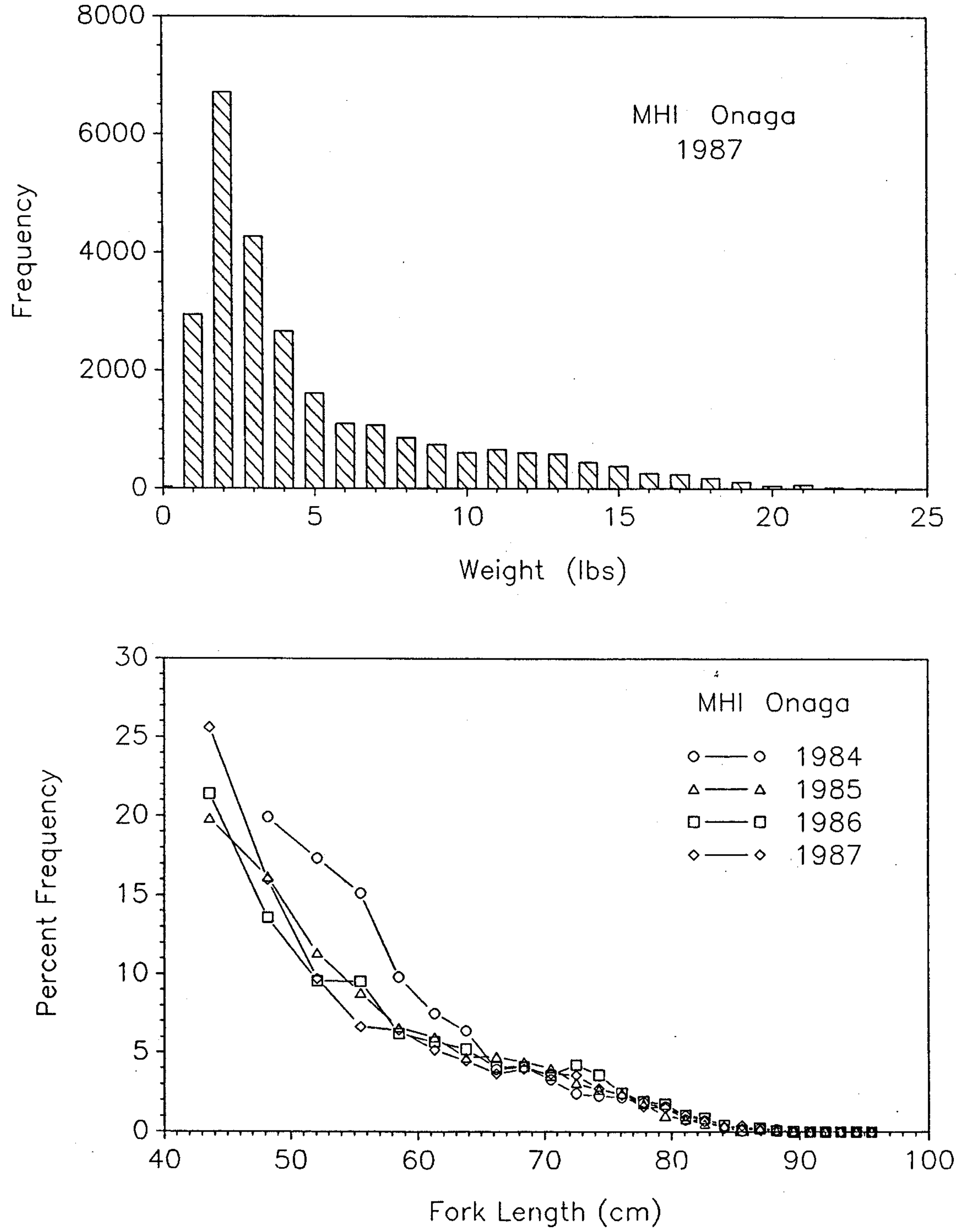


Figure 10.--Weight-frequency distribution of main Hawaiian Islands (MHI) onaga based upon 1987 market samples (upper panel) and descending limbs of estimated relative length-frequency distributions for each year from 1984 to 1987 (lower panel).

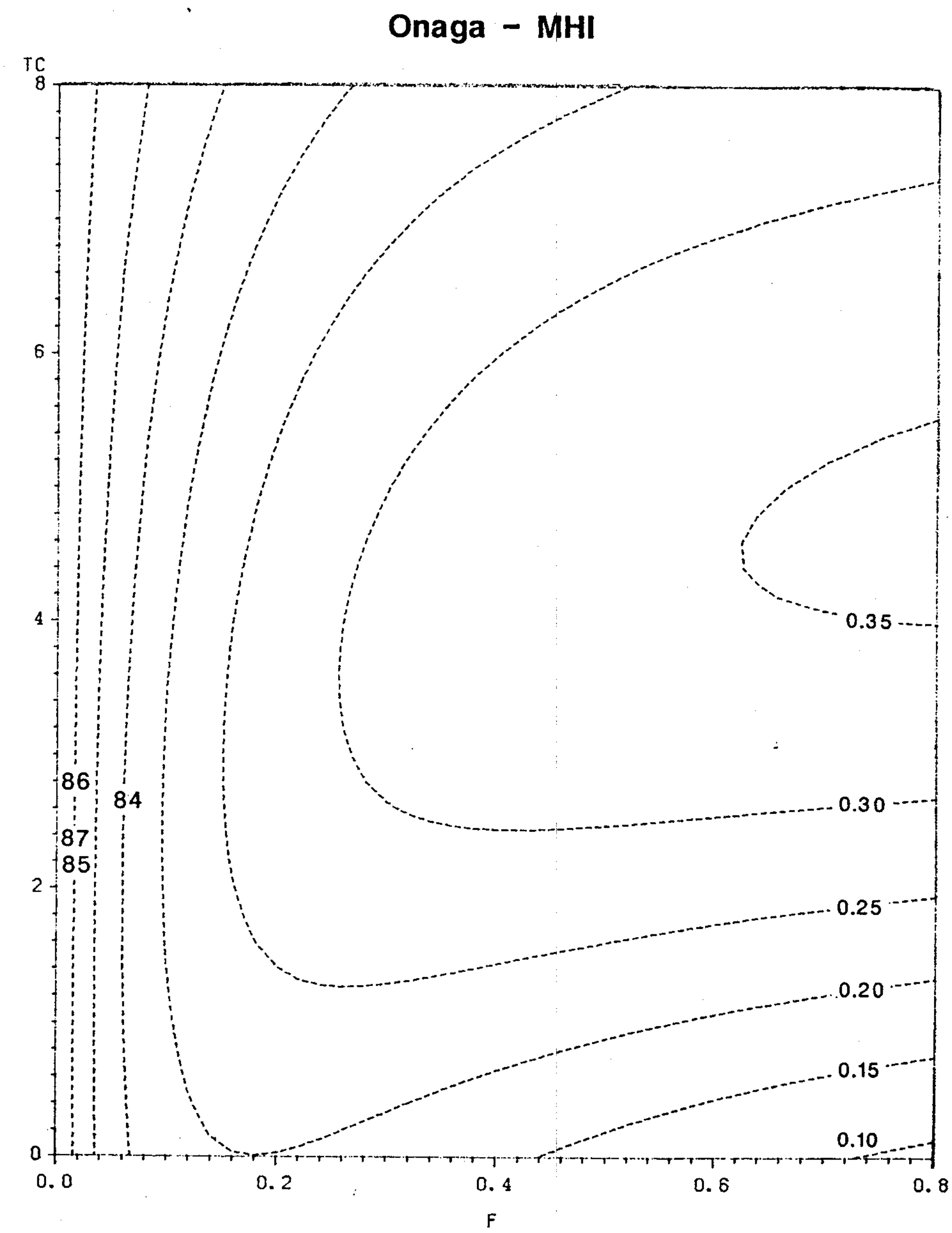


Figure 11.--Yield-per-recruit analysis for main Hawaiian Islands (MHI) onaga (1984-87). The unit of fishing mortality (*F*) is yr^{-1}, and the unit of age at entry (t_c) is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (in kilograms). Changes within the fishery are shown on an annual basis.

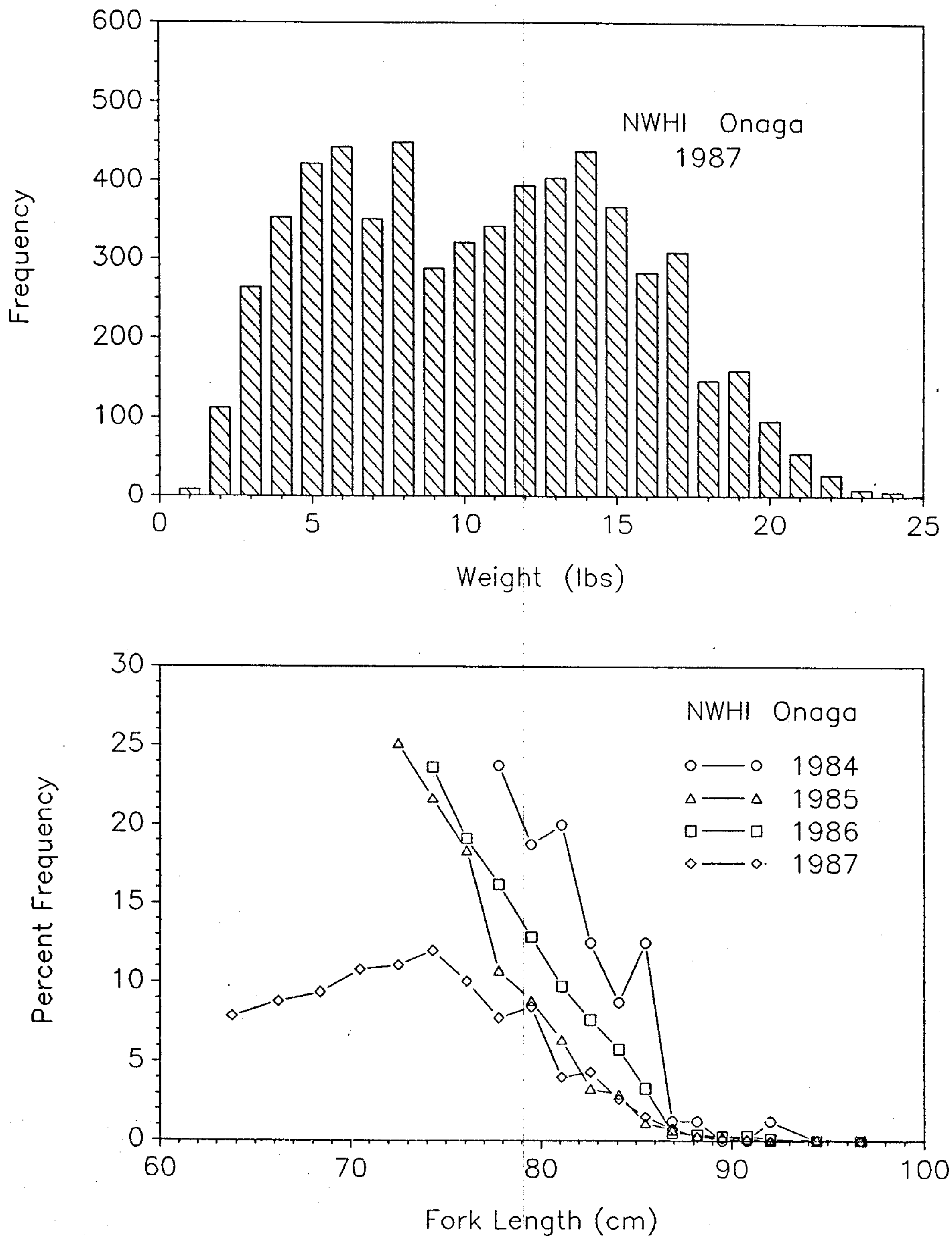


Figure 12.--Weight-frequency distribution of Northwestern Hawaiian Islands (NWHI) onaga based upon 1987 market samples (upper panel) and descending limbs of estimated relative length-frequency distributions for each year from 1984 to 1987 (lower panel).

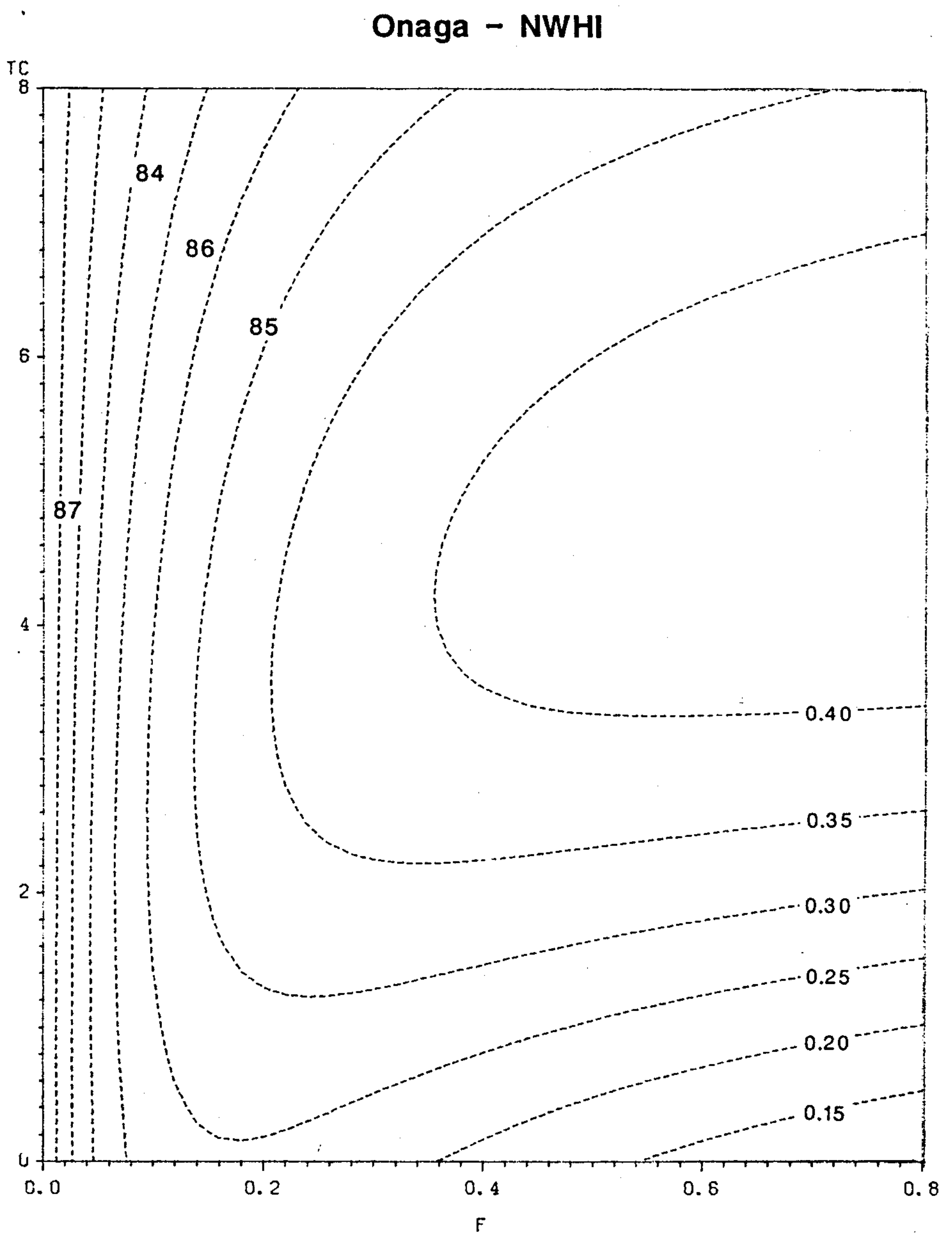


Figure 13.--Yield-per-recruit analysis for Northwestern Hawaiian Islands (NWHI) onaga (1984-87). The unit of fishing mortality (*F*) is yr^{-1}, and the unit of age at entry ($\underline{t_c}$) is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (in kilograms). Changes within the fishery are shown on an annual basis.

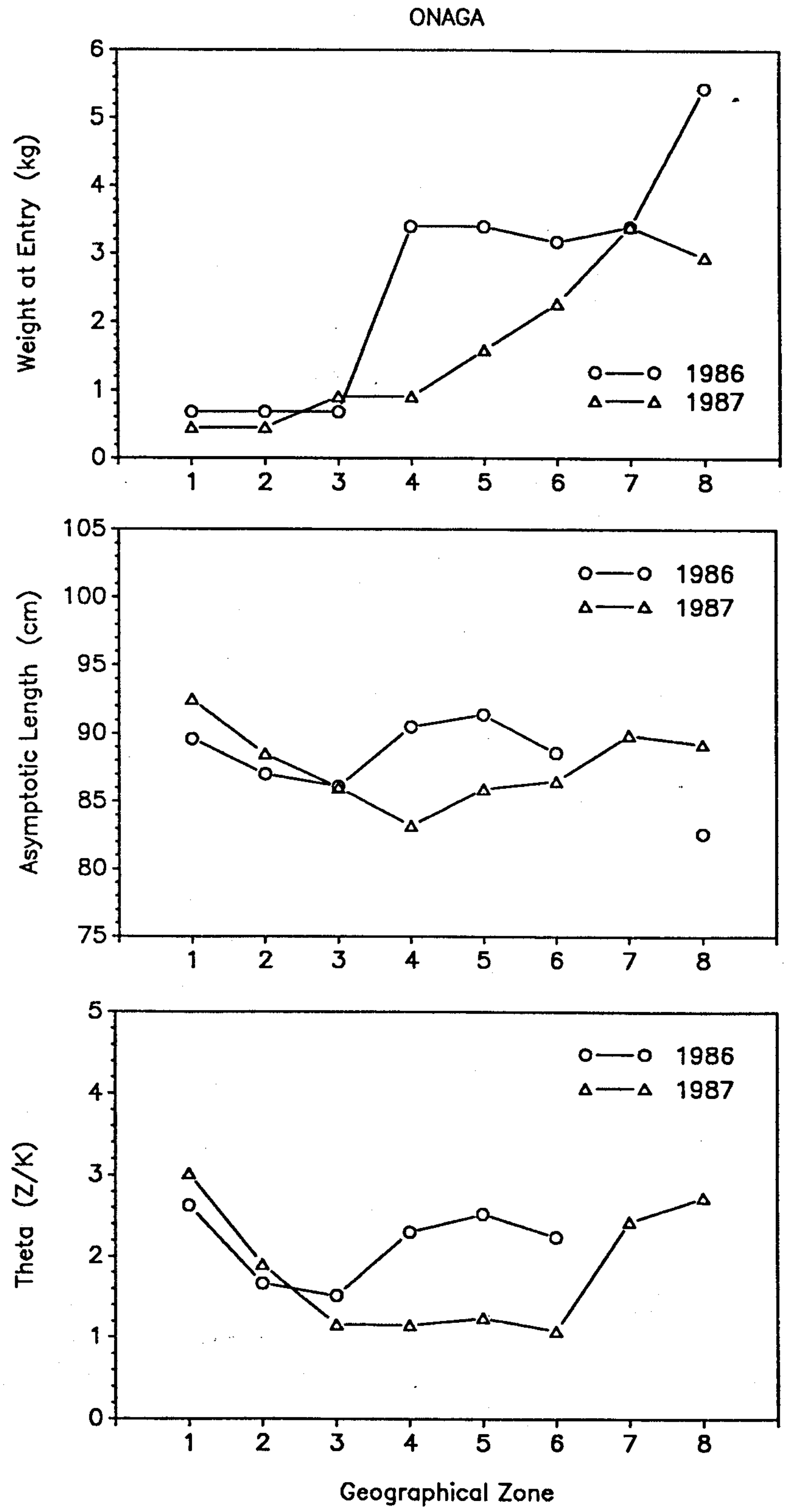


Figure 14.--Relationship of critical onaga fishery statistics to geographical zone (see Table 5). Shown are estimates of weight at entry, asymptotic length, and mortality to growth ratio (theta ($\underline{Z}/\underline{K}$)) for the years 1986 and 1987.

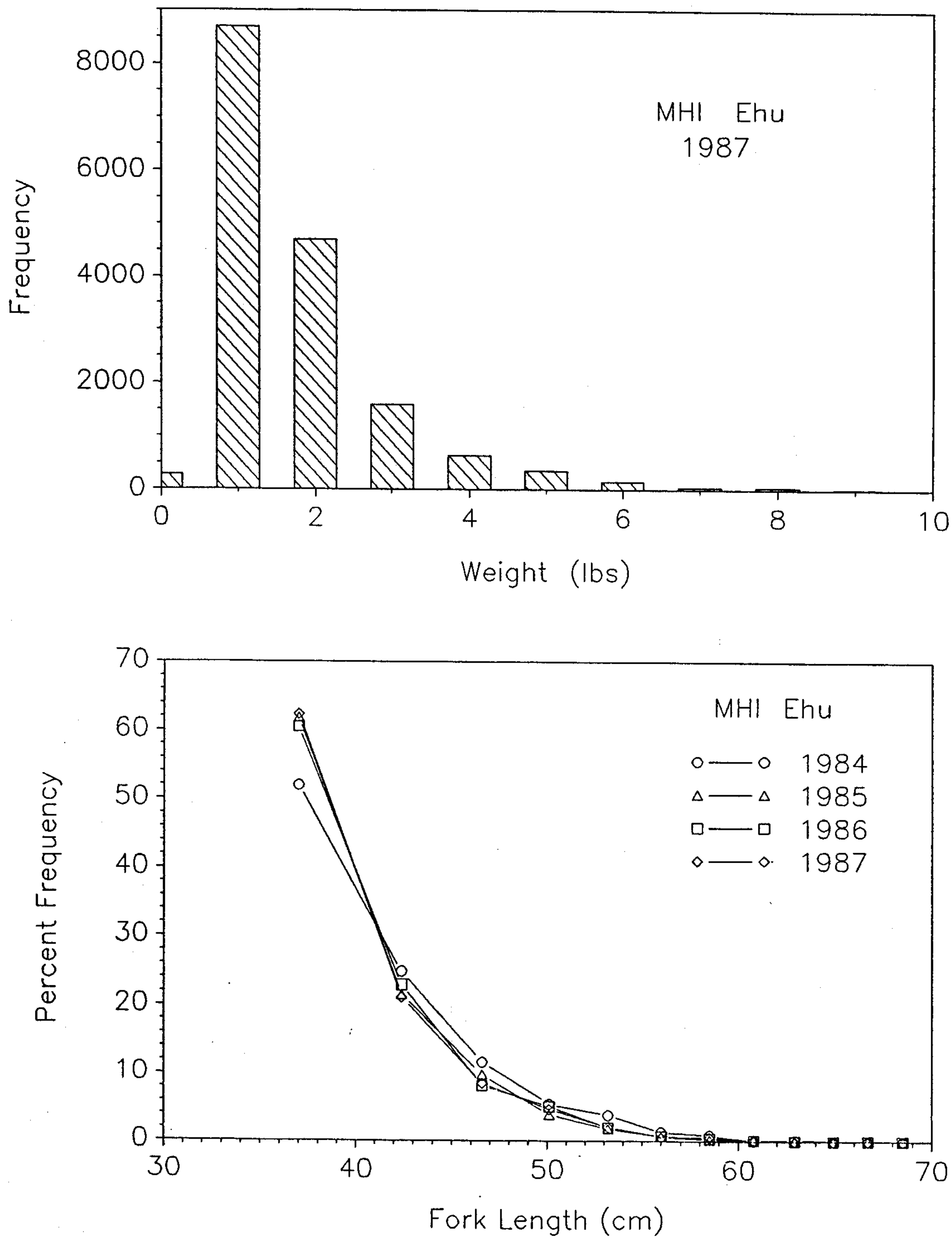


Figure 15.--Weight-frequency distribution of main Hawaiian Islands (MHI) ehu based upon 1987 market samples (upper panel) and descending limbs of estimated relative length-frequency distributions for each year from 1984 to 1987 (lower panel).

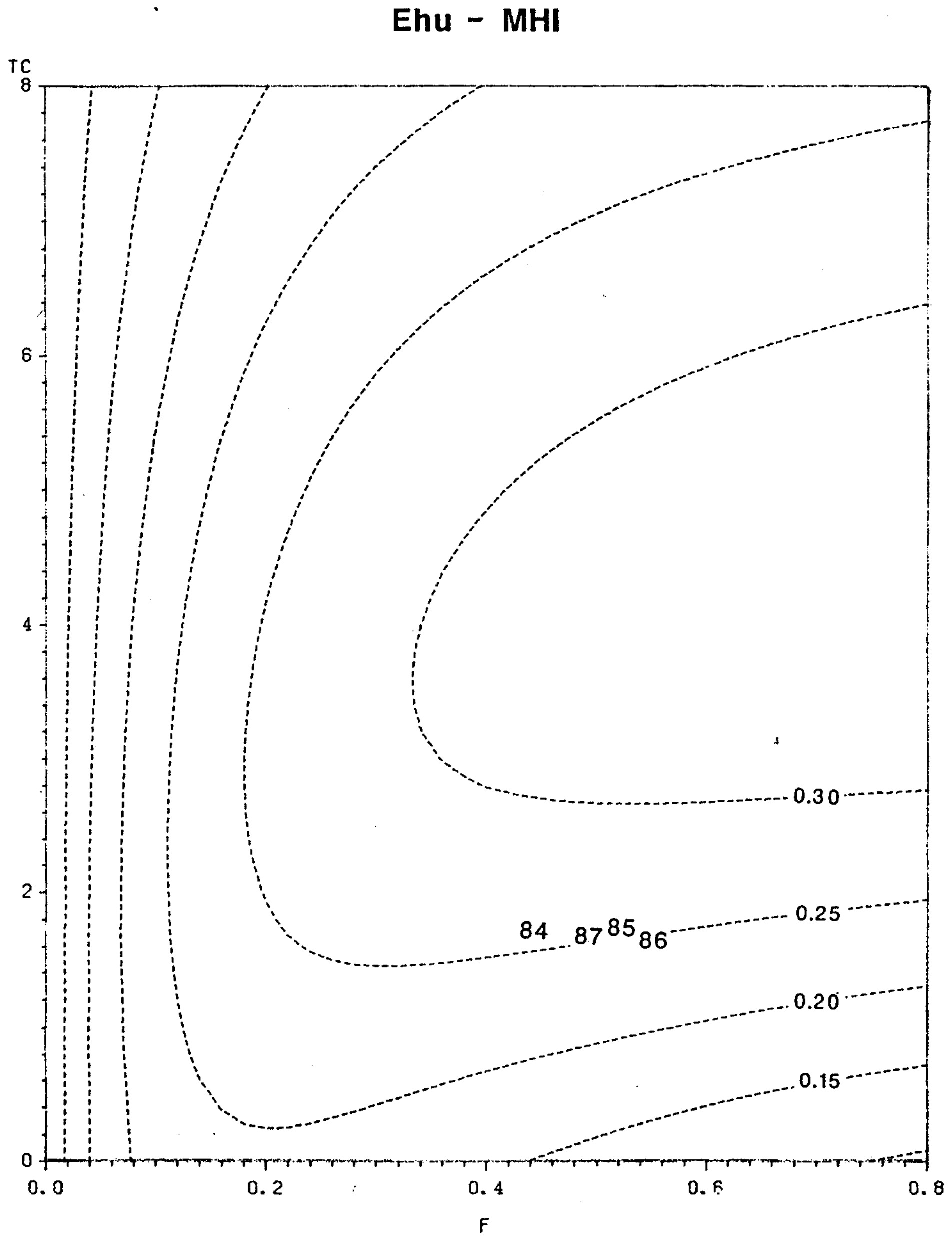


Figure 16.--Yield-per-recruit analysis for main Hawaiian Islands (MHI) ehu (1984-87). The unit of ($\underline{F}$) is yr^{-1}, and the unit of age at entry ($\underline{t}_c$) is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (in kilograms). Changes within the fishery are shown on an annual basis.

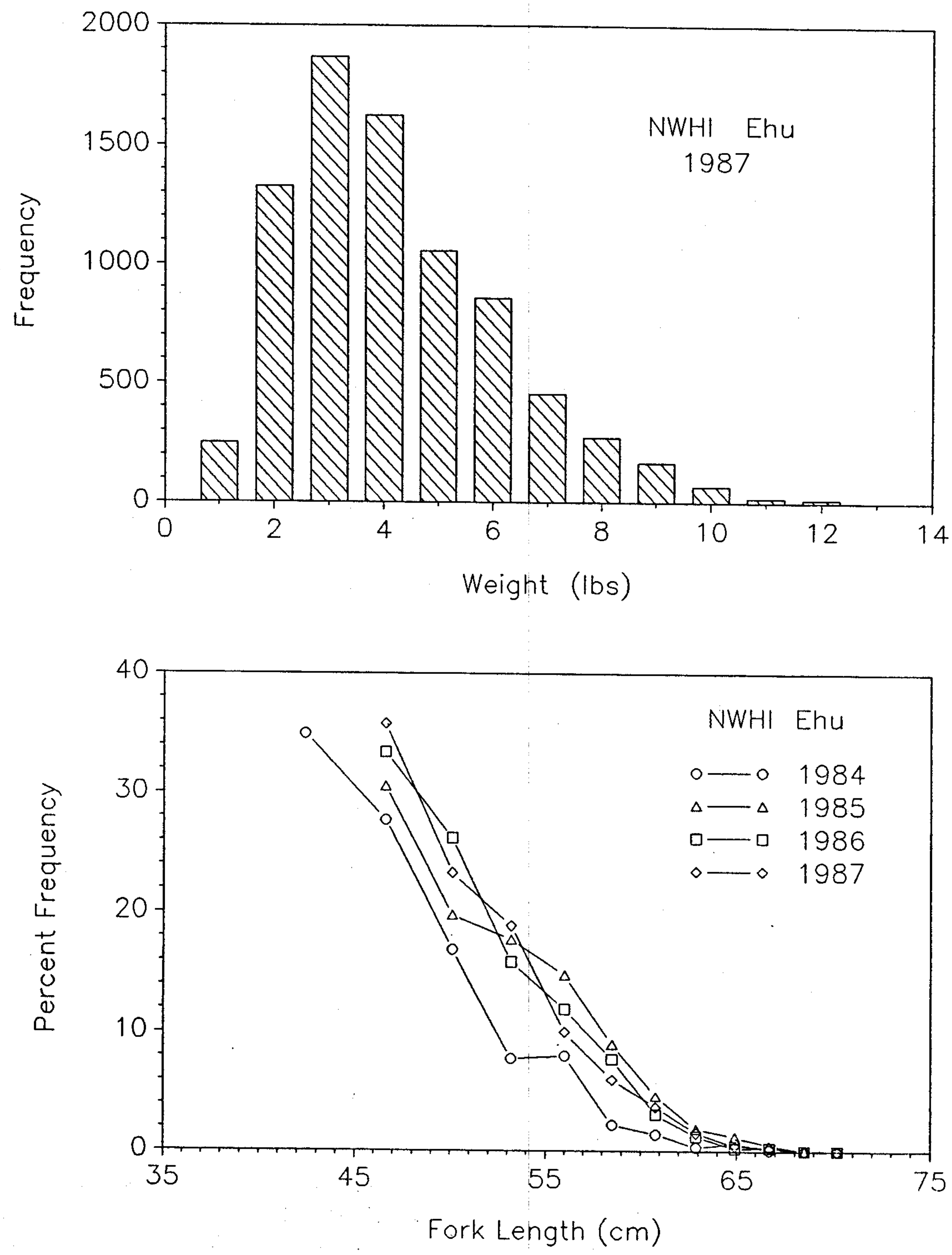


Figure 17.--Weight-frequency distribution of Northwestern Hawaiian Islands (NWHI) ehu based upon 1987 market samples (upper panel) and descending limbs of estimated relative length-frequency distributions for each year from 1984 to 1987 (lower panel).

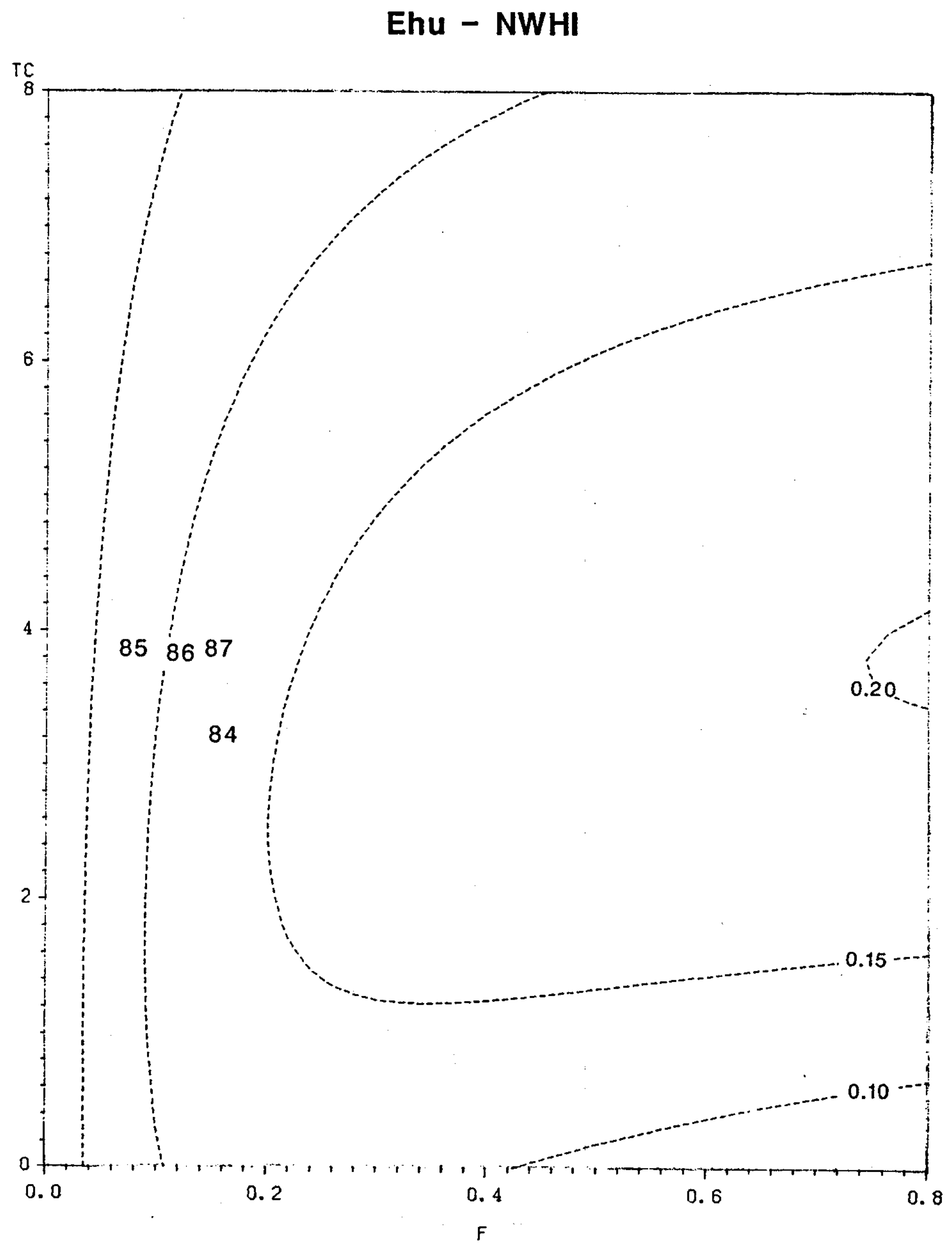


Figure 18.--Yield-per-recruit analysis for Northwestern Hawaiian Islands (NWHI) ehu (1984-87). The unit of ($\underline{F}$) is yr^{-1}, and the unit of age at entry ($\underline{t}_c$) is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (in kilograms). Changes within the fishery are shown on an annual basis.

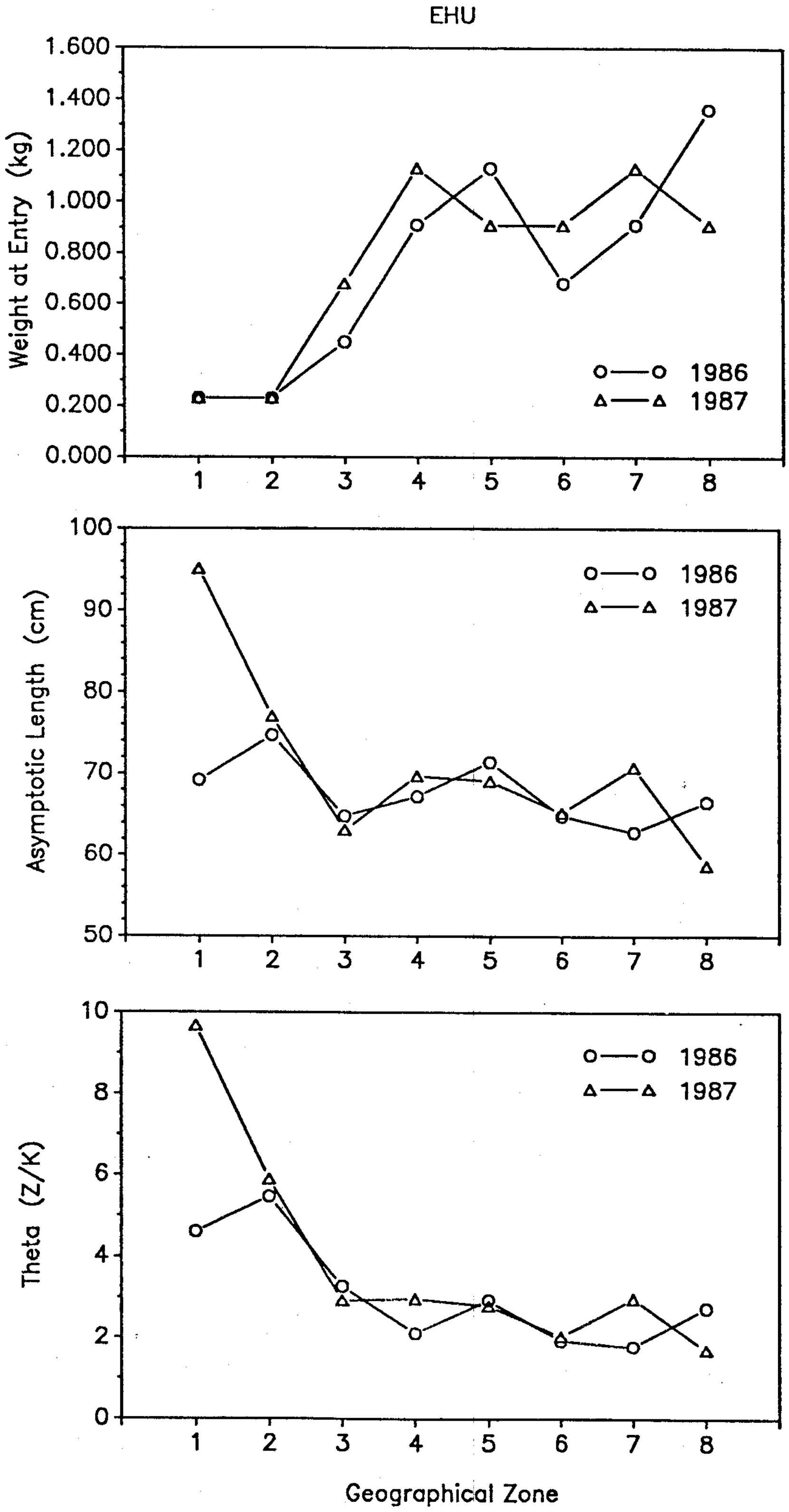


Figure 19.--Relationship of critical ehu fishery statistics to geographical zone (see Table 5). Shown are estimates of weight at entry, asymptotic length, and mortality to growth ratio (theta (_Z_/_K_)) for the years 1986 and 1987.

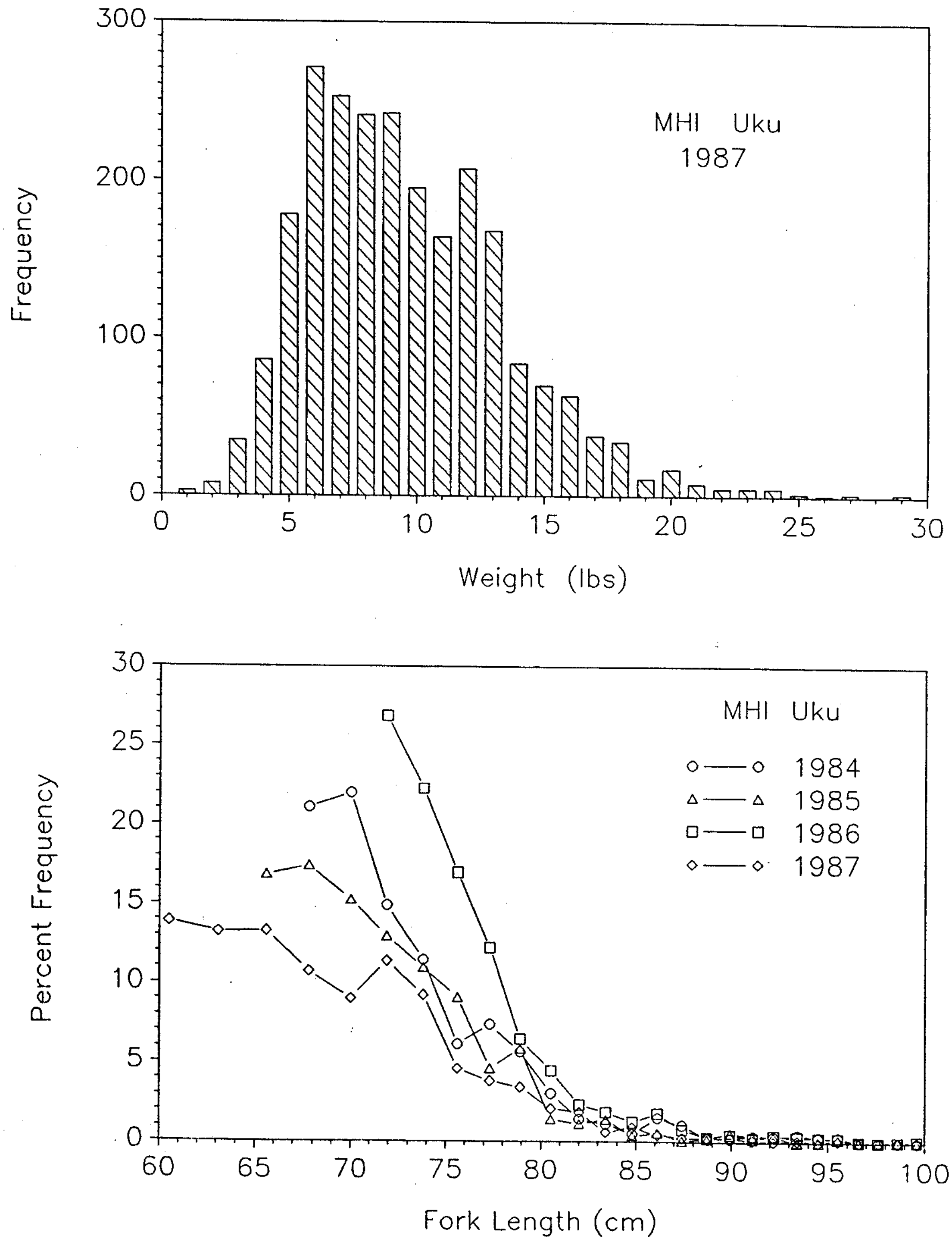


Figure 20.--Weight-frequency distribution of main Hawaiian Islands (MHI) uku based upon 1987 market samples (upper panel) and descending limbs of estimated relative length-frequency distributions for each year from 1984 to 1987 (lower panel).

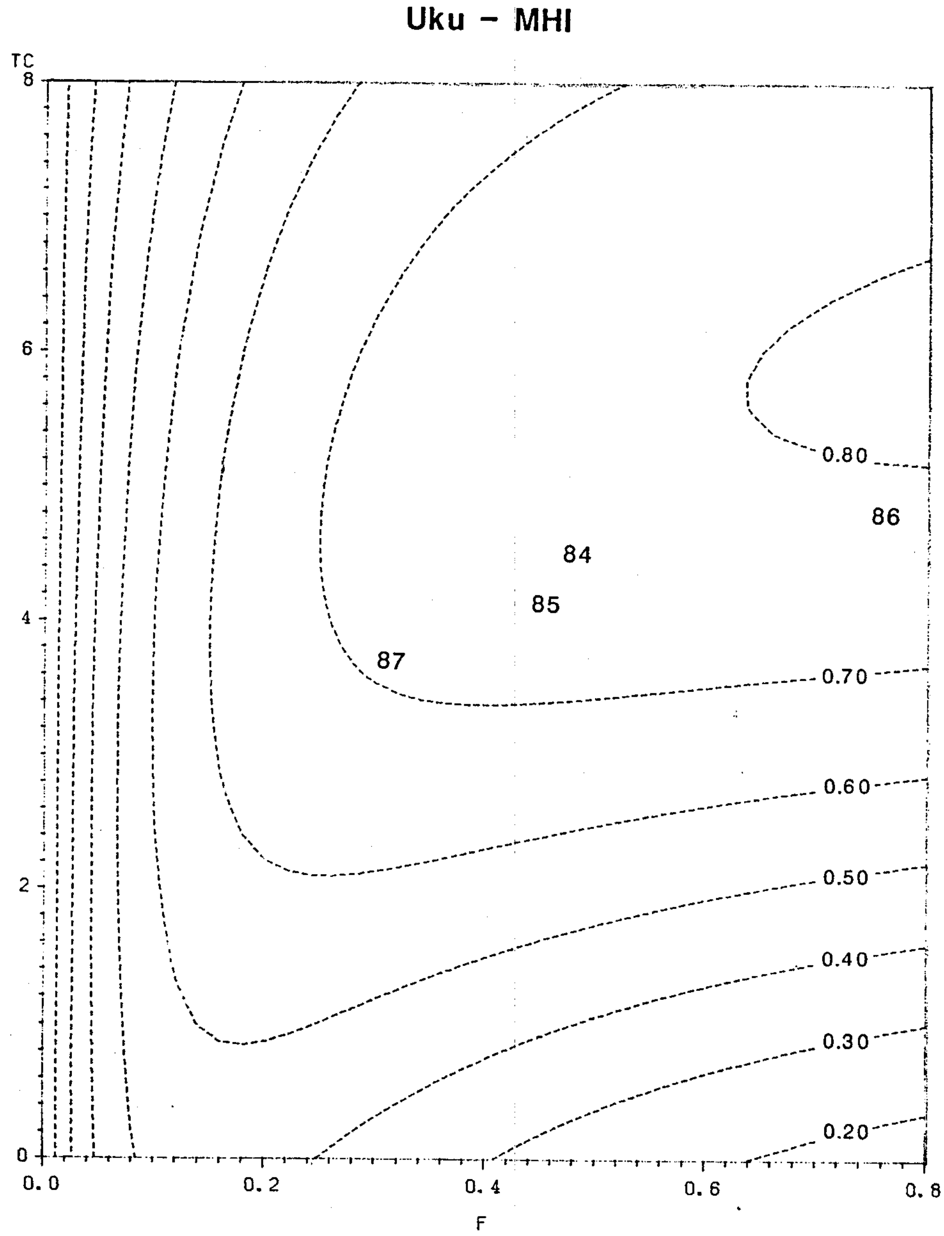


Figure 21.--Yield-per-recruit analysis for main Hawaiian Islands (MHI) uku (1984-87). The unit of fishing mortality (F) is yr^{-1}, and the unit of age at entry (T_c) is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (in kilograms). Changes within the fishery are shown on an annual basis.

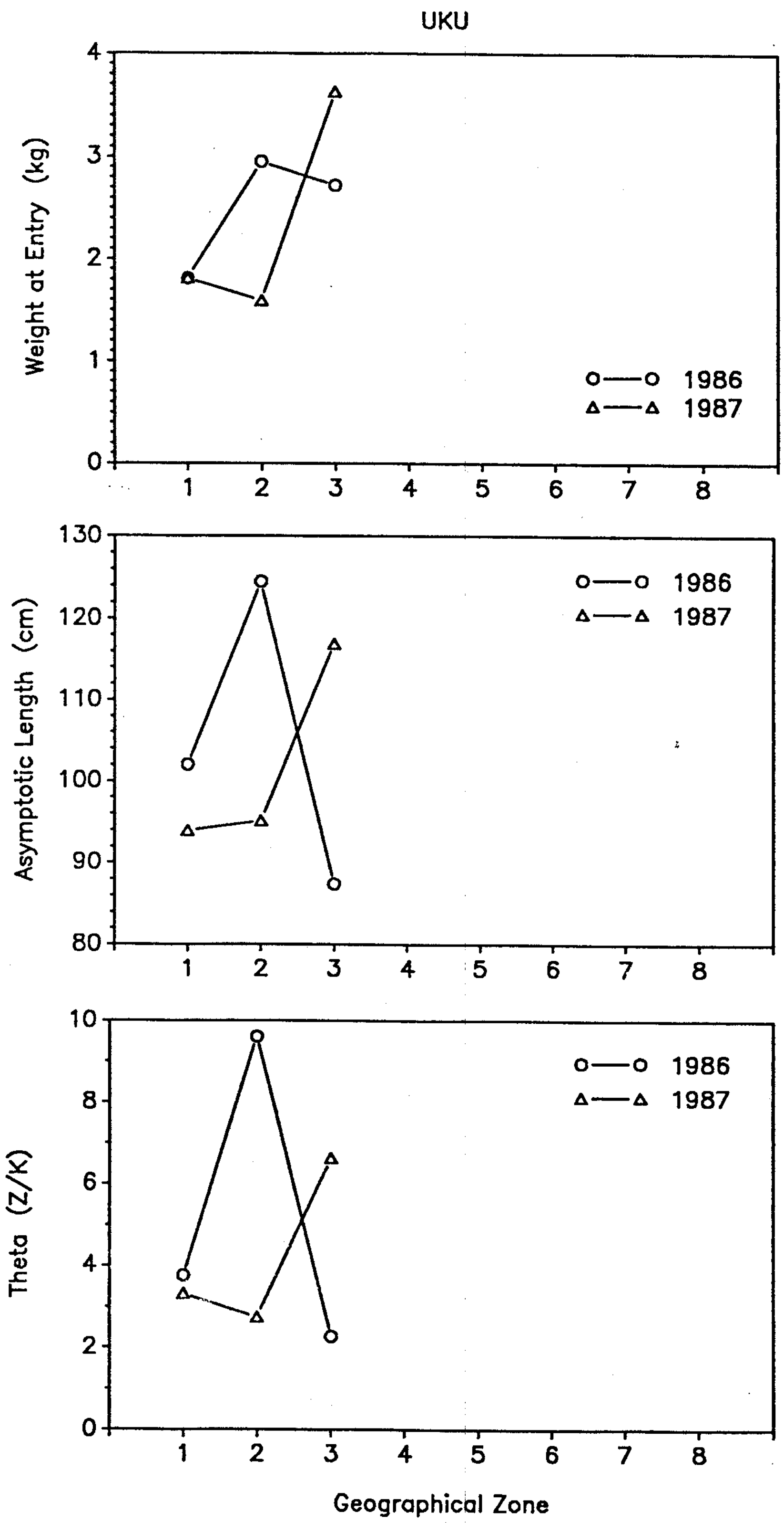


Figure 22.--Relationship of critical uku fishery statistics to geographical zone (see Table 5). Shown are estimates of weight at entry, asymptotic length, and mortality to growth ratio (theta ($\underline{Z}/\underline{K}$)) for the years 1986 and 1987.

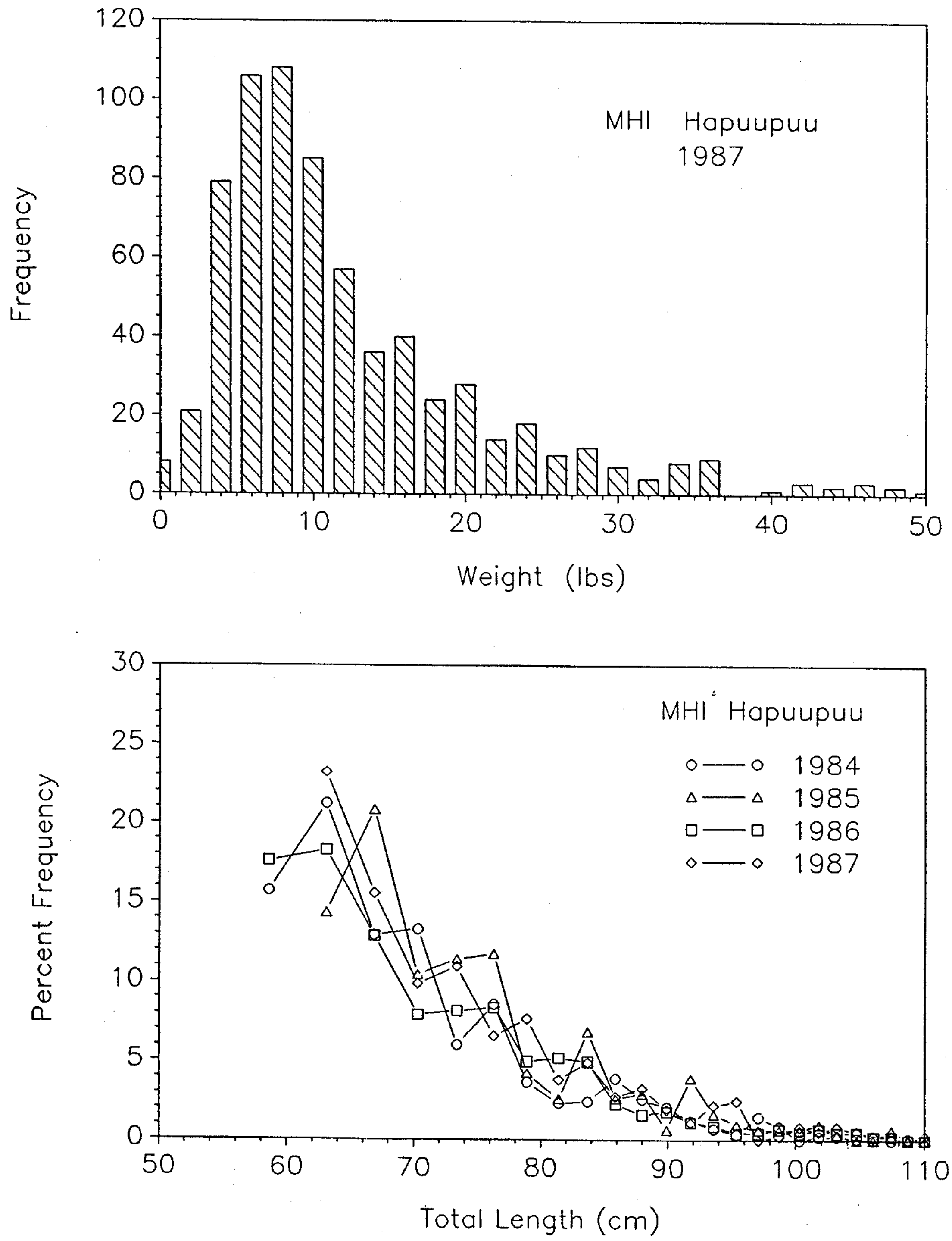


Figure 23.--Weight-frequency distribution of main Hawaiian Islands (MHI) hapuupuu based upon 1987 market samples (upper panel) and descending limbs of estimated relative length-frequency distributions for each year from 1984 to 1987 (lower panel).

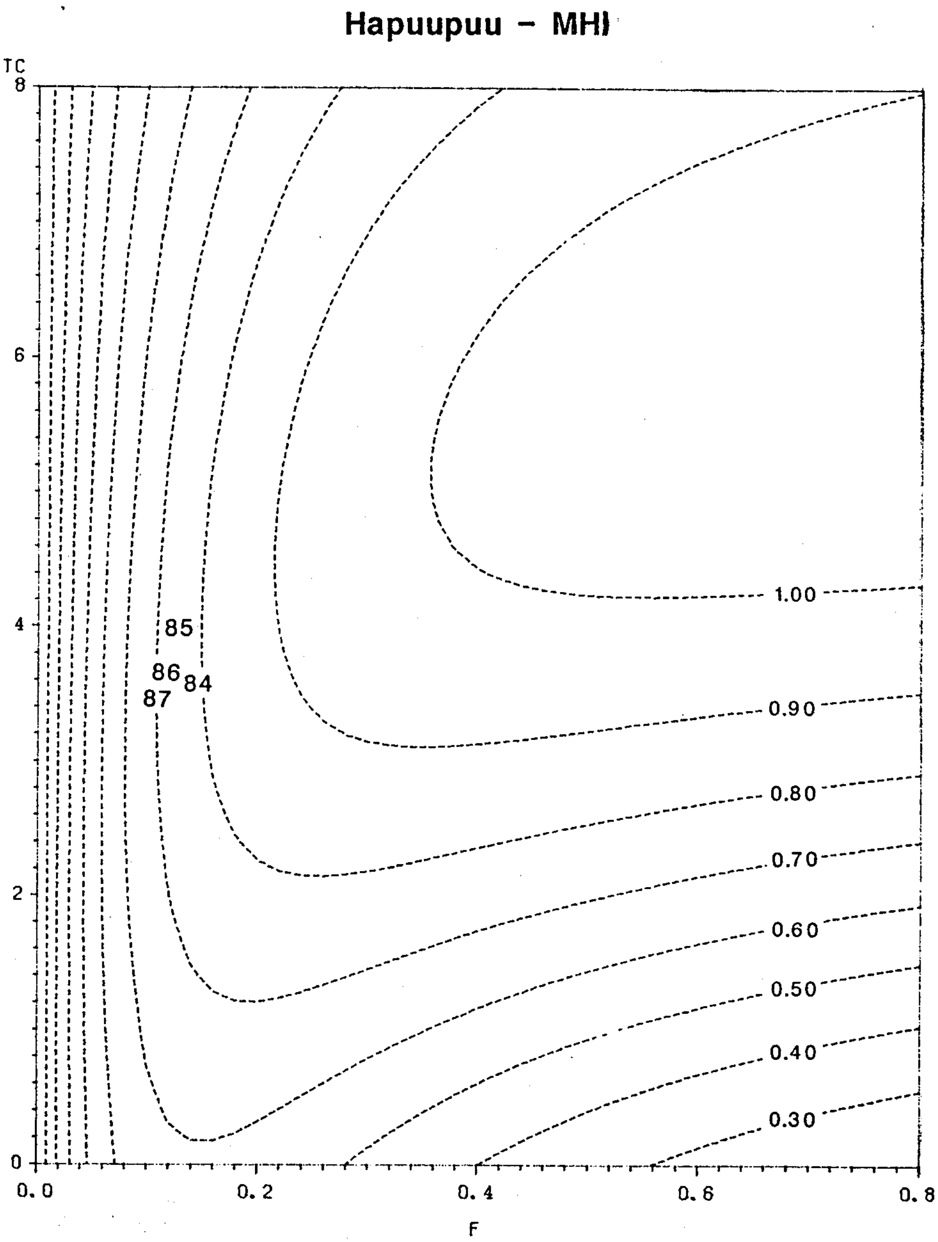


Figure 24.--Yield-per-recruit analysis for main Hawaiian Islands (MHI) hapuupuu (1984-87). The unit of (*F*) is yr^{-1}, and the unit of age at entry (t_c) is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (in kilograms). Changes within the fishery are shown on an annual basis.

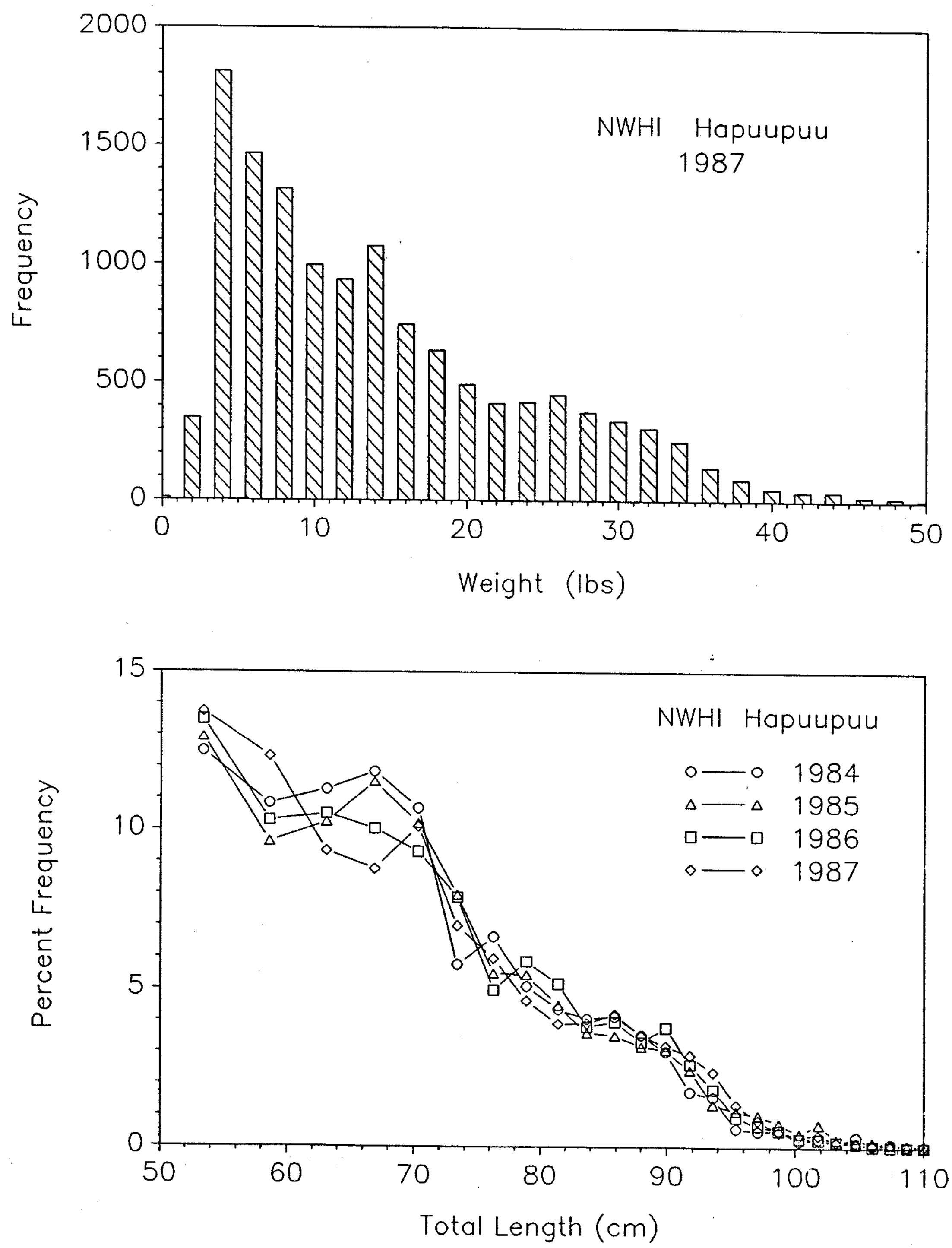


Figure 25.--Weight-frequency distribution of Northwestern Hawaiian Islands (NWHI) hapuupuu based upon 1987 market samples (upper panel) and descending limbs of estimated from relative length-frequency distributions for each year 1984 to 1987 (lower panel).

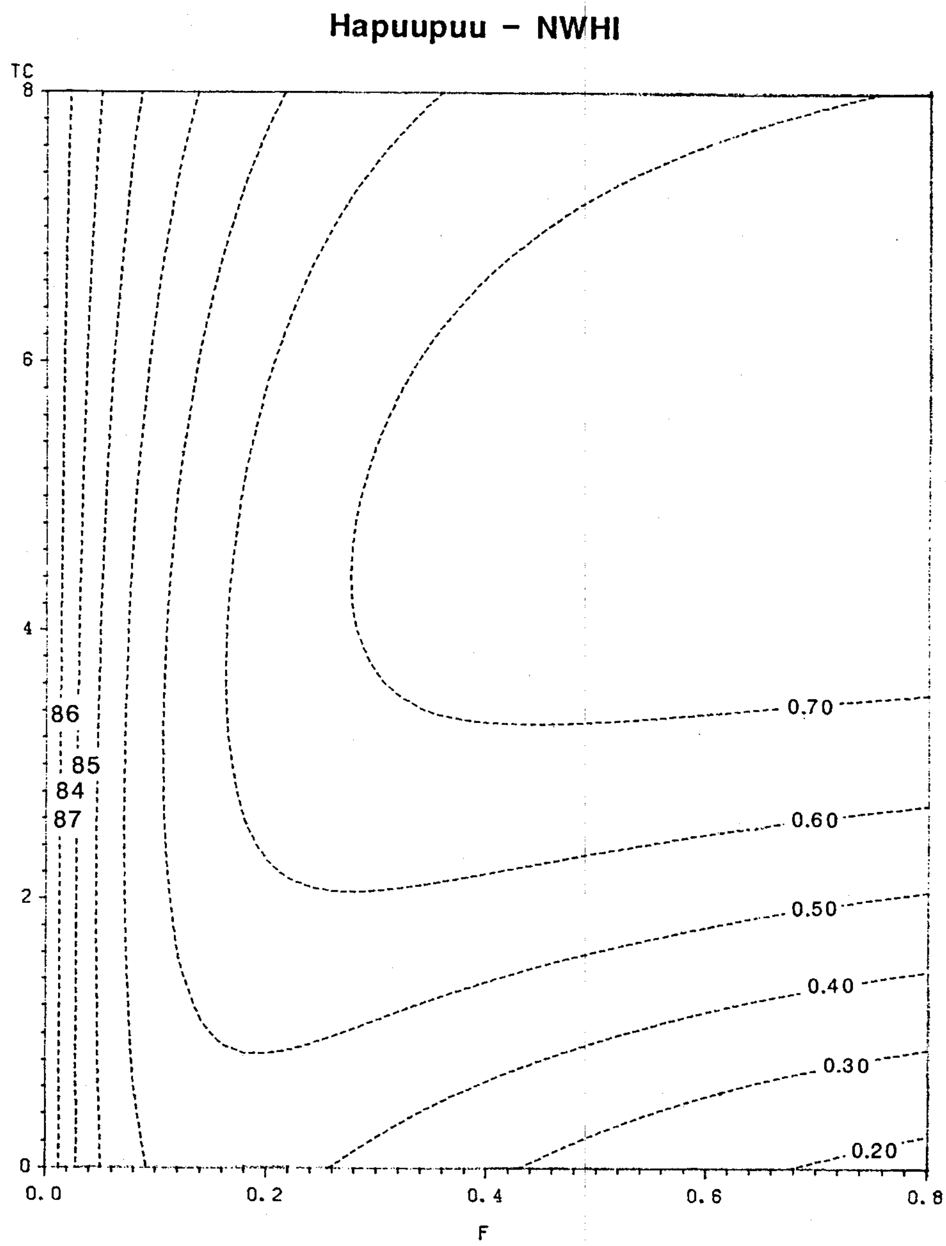


Figure 26.--Yield-per-recruit analysis for Northwestern Hawaiian Islands (NWHI) hapuupuu (1984-87). The unit of (_F_) is yr^{-1}, and the unit of age at entry (t_c) is years. Contoured isopleths represent the locus of points corresponding to equal yield per recruit (in kilograms). Changes within the fishery are shown on an annual basis.

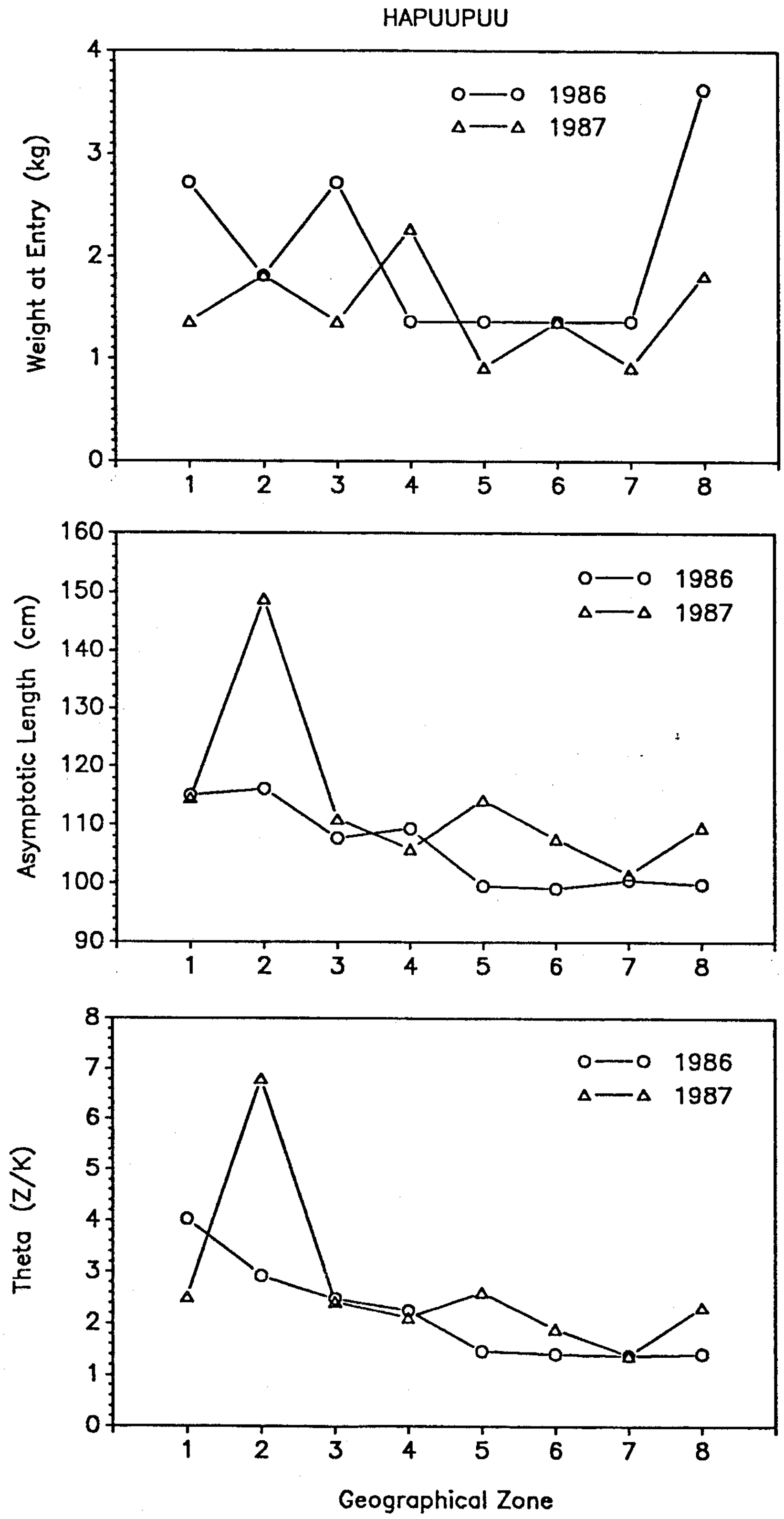


Figure 27.--Relationship of critical hapuupuu fishery statistics to geographical zone (see Table 5). Shown are estimates of weight at entry, asymptotic length, and mortality to growth ratio (theta (Z/K)) for the years 1986 and 1987.

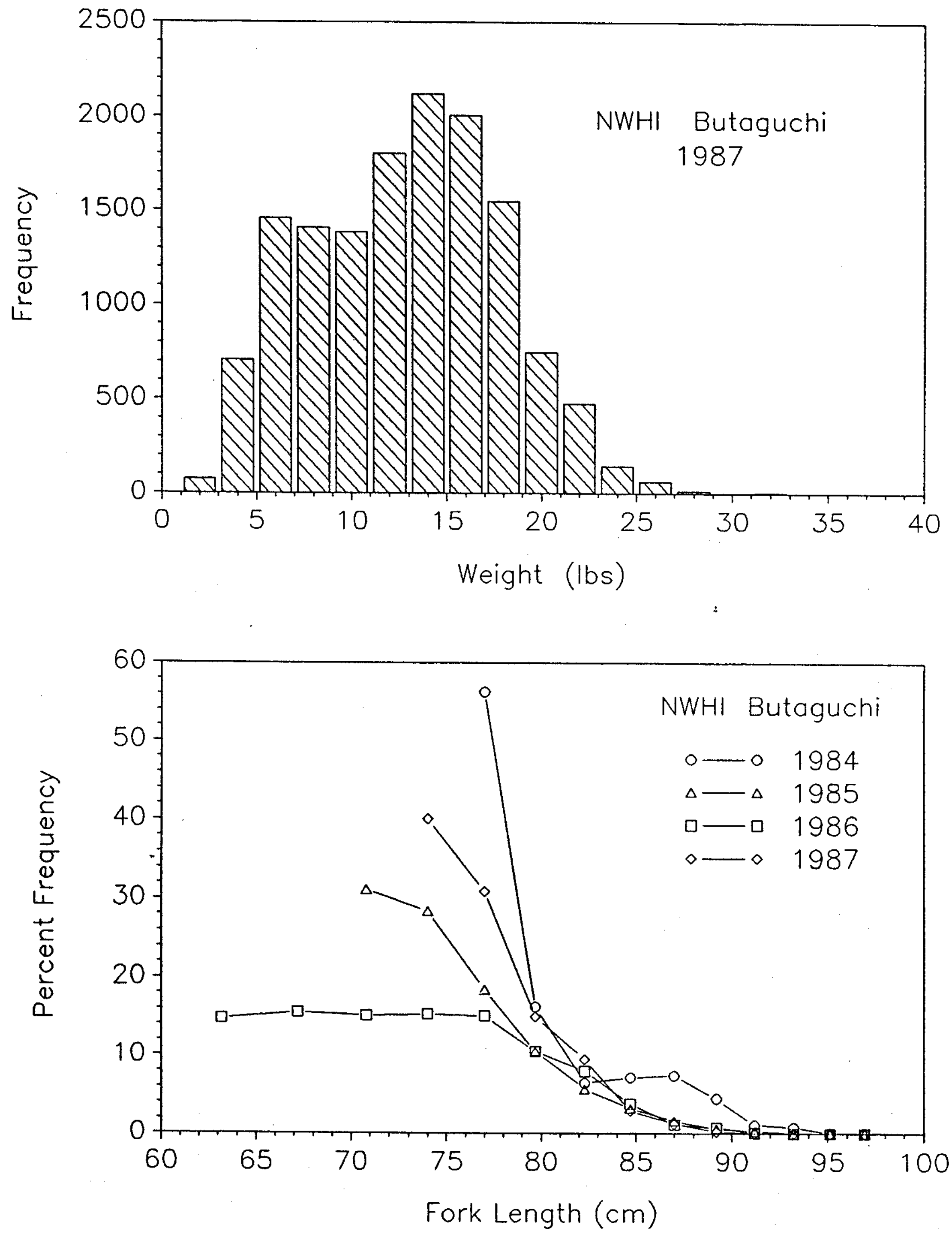


Figure 28.--Weight-frequency distribution of Northwestern Hawaiian Islands (NWHI) butaguchi based upon 1987 market samples (upper panel) and descending limbs of estimated relative length-frequency distributions for each year from 1984 to 1987 (lower panel).

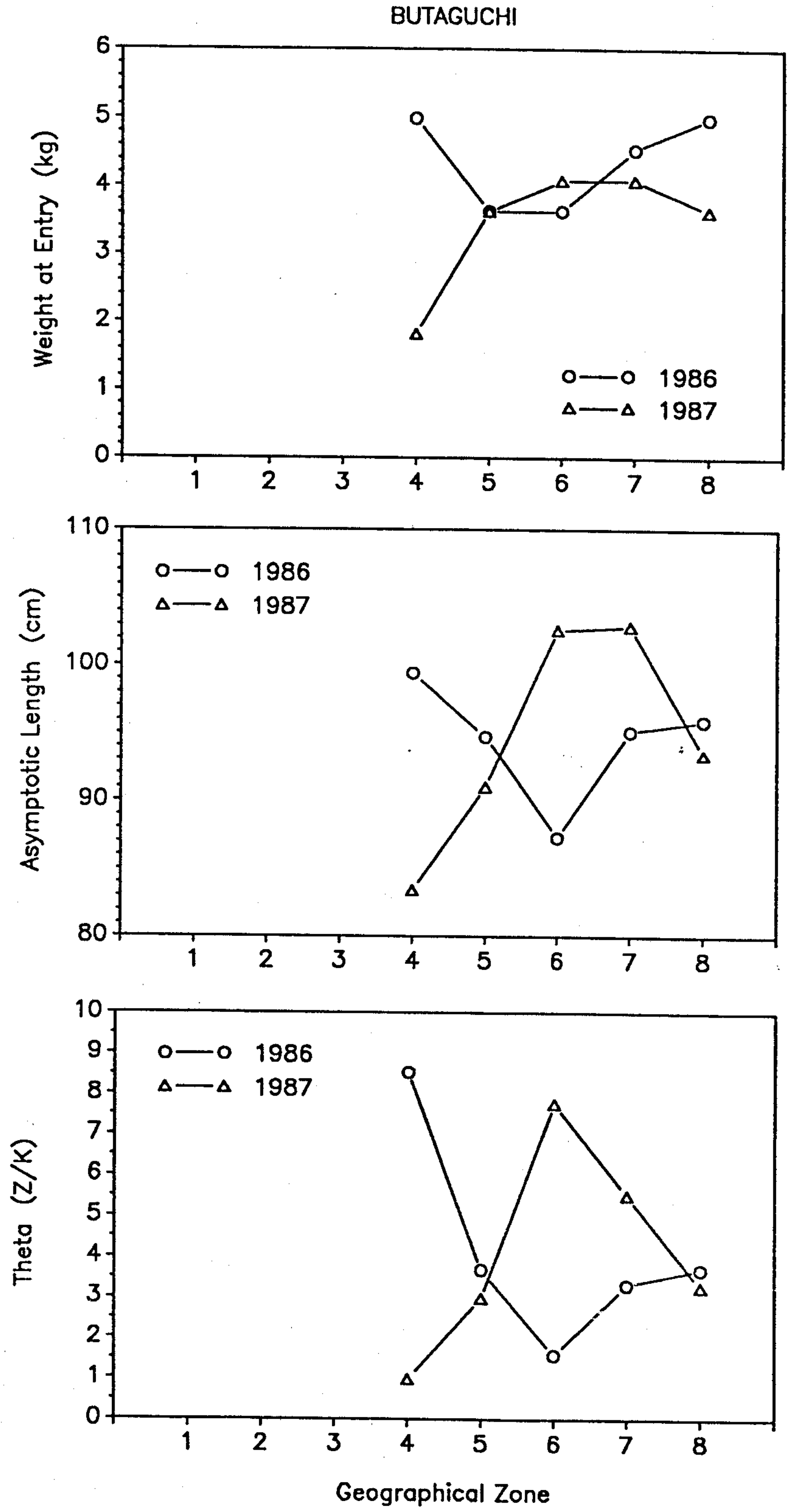


Figure 29.--Relationship of critical butaguchi fishery statistics to geographical zone (see Table 5). Shown are estimates of weight at entry, asymptotic length, and mortality to growth ratio (theta ($\underline{Z}/\underline{K}$)) for the years 1986 and 1987.

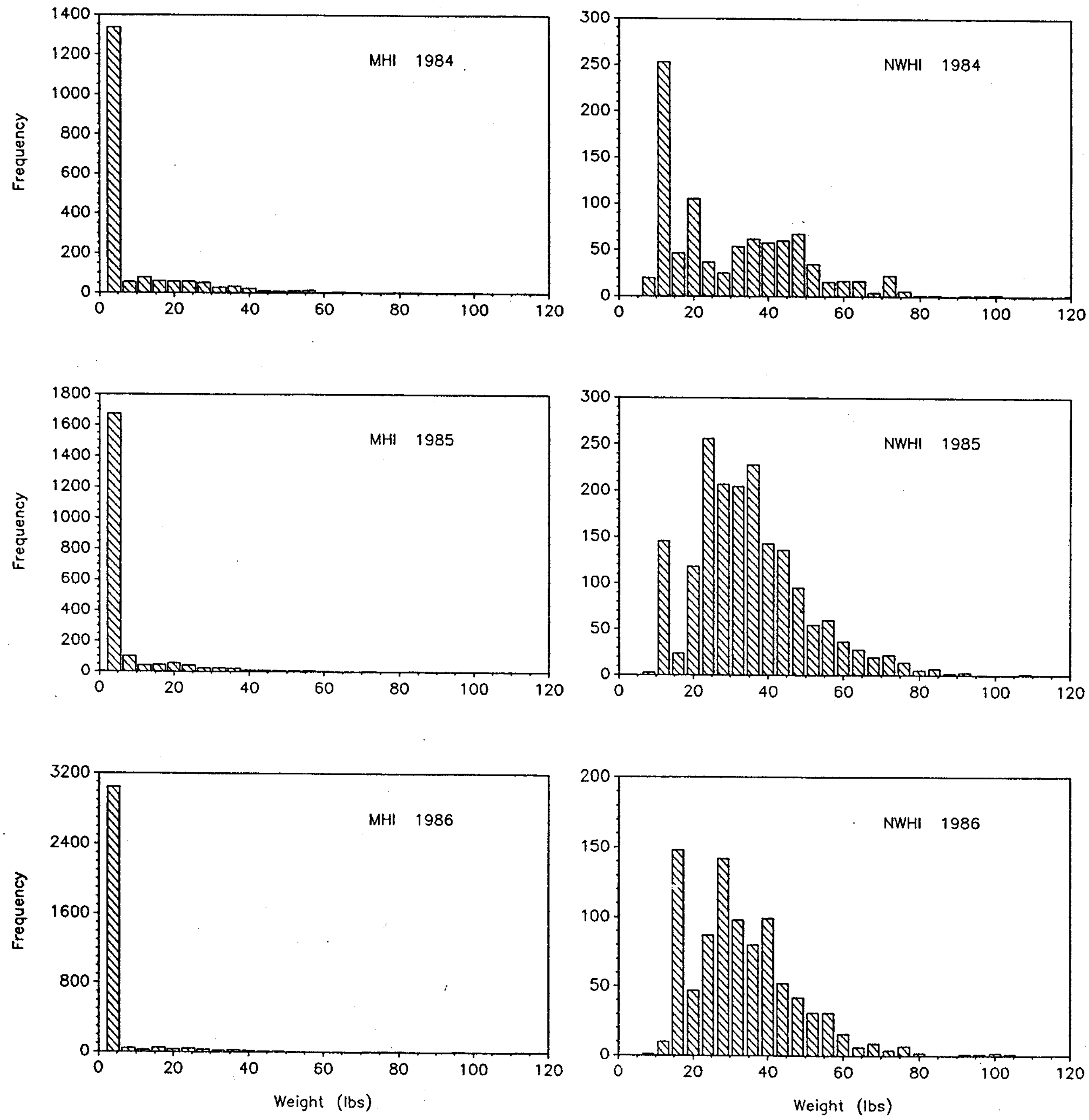


Figure 30.--Weight-frequency distributions of main Hawaiian Islands (MHI) and Northwestern Hawaiian Islands (NWHI) white ulua based upon market samples obtained from 1984 to 1986.

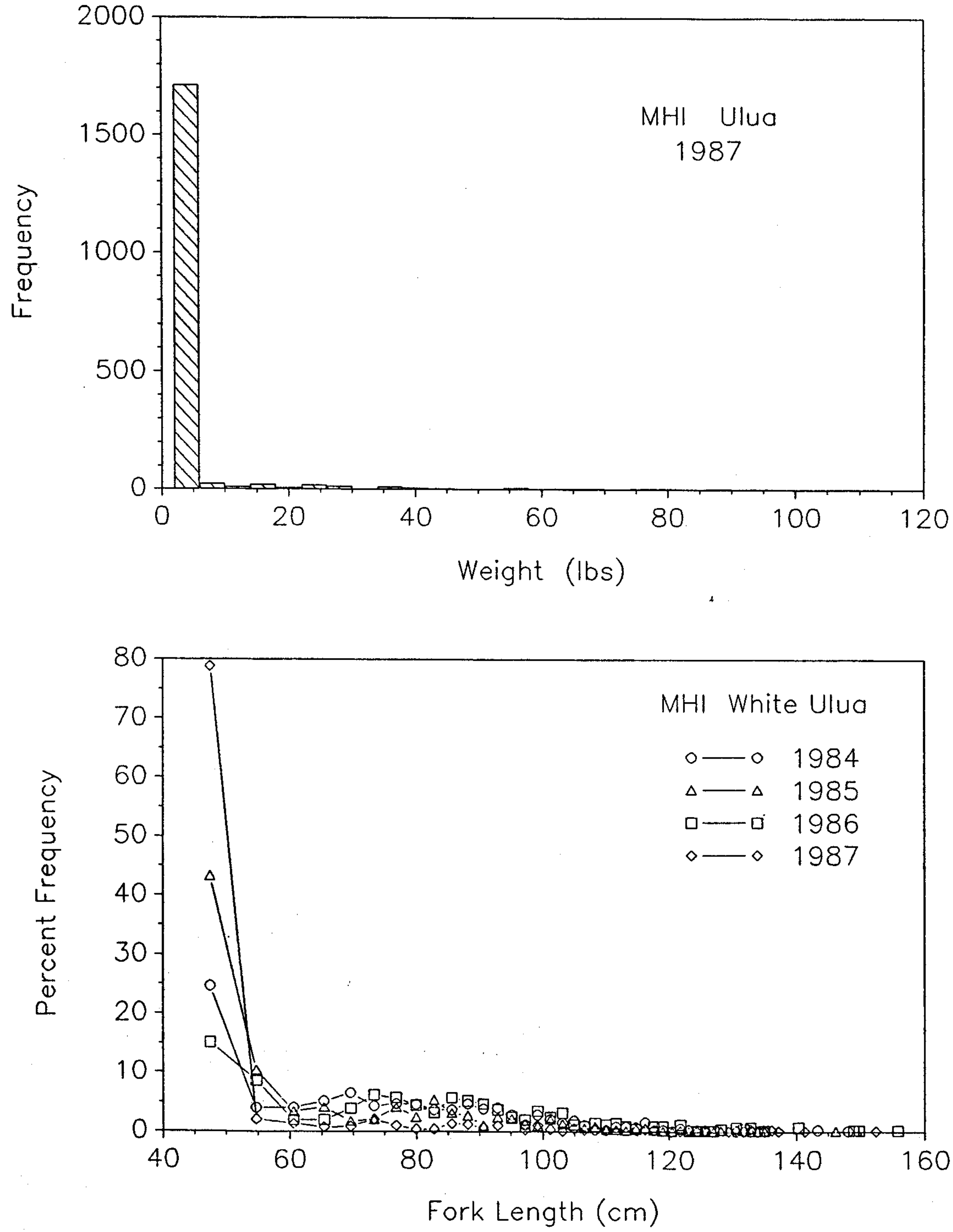


Figure 31.--Weight-frequency distribution of main Hawaiian Islands (MHI) white ulua based upon 1987 market samples (upper panel) and descending limbs of estimated relative length-frequency distributions for each year from 1984 to 1987 (lower panel).

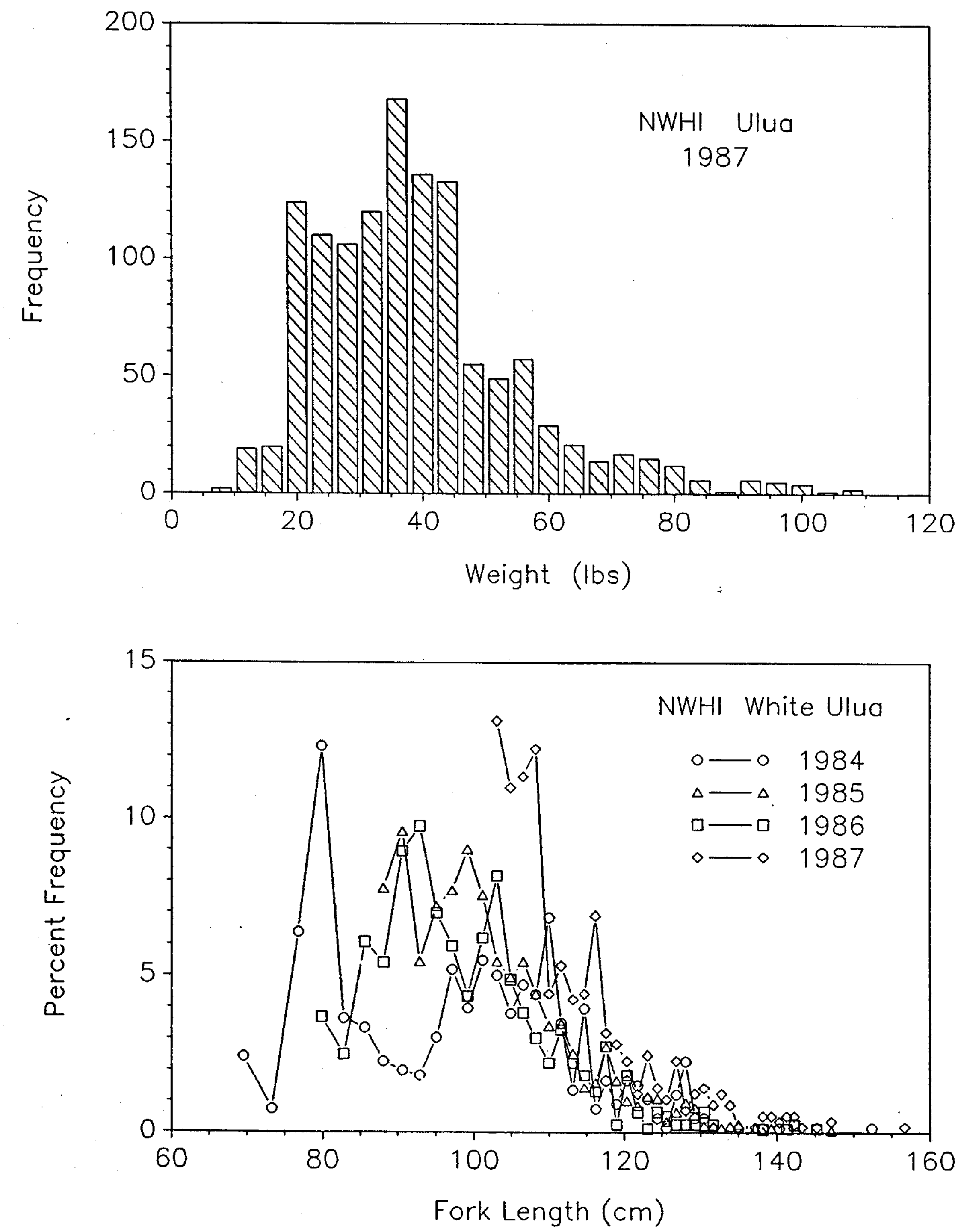


Figure 32.--Weight-frequency distribution of Northwestern Hawaiian Islands (NWHI) white ulua based upon 1987 market samples (upper panel) and descending limbs of estimated relative length-frequency distributions for each year from 1984 to 1987 (lower panel).

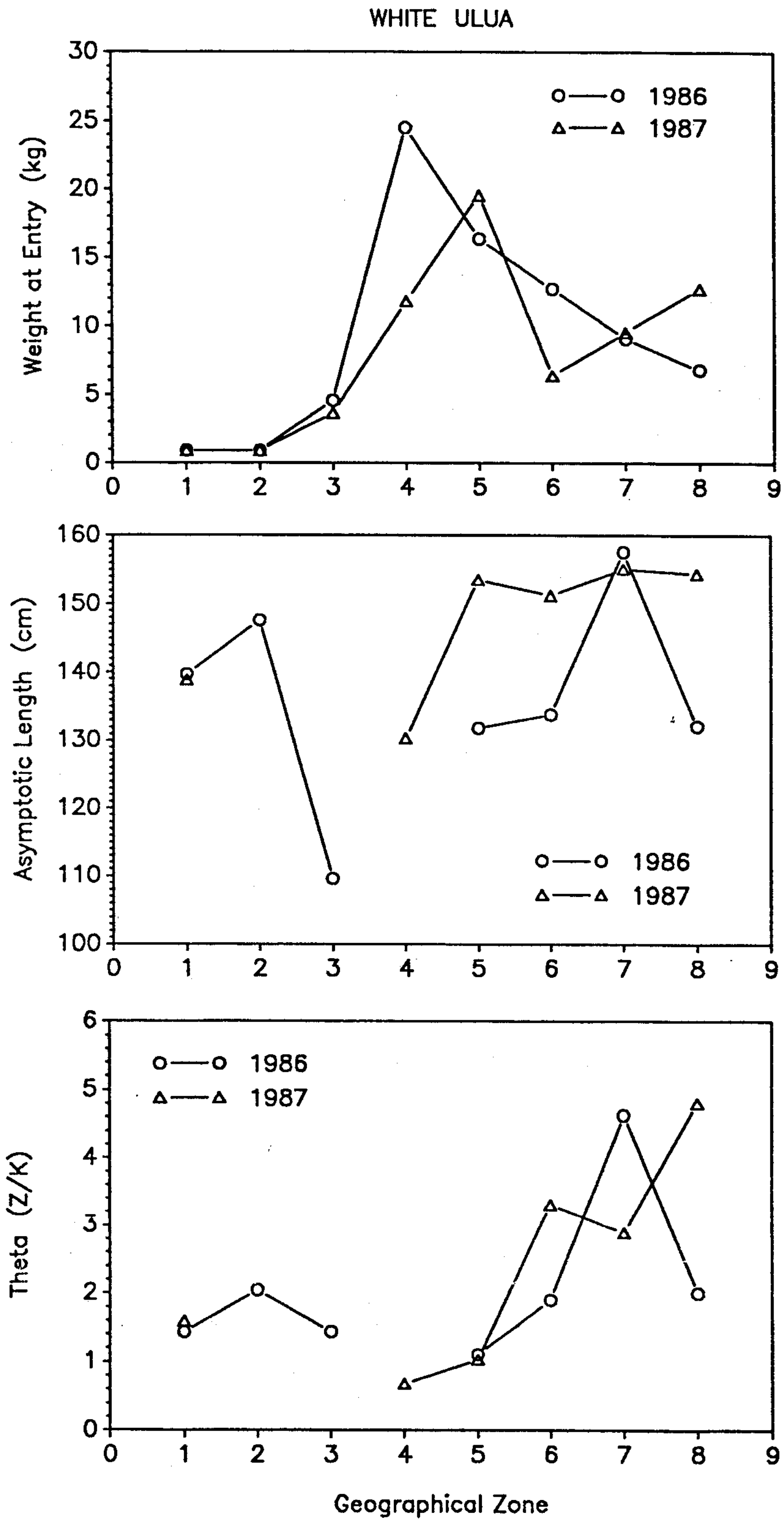


Figure 33.--Relationship of critical white ulua fishery statistics to geographical zone (see Table 5). Shown are estimates of weight at entry, asymptotic length, and mortality to growth ratio (theta ($\underline{Z}/\underline{K}$)) for the years 1986 and 1987.

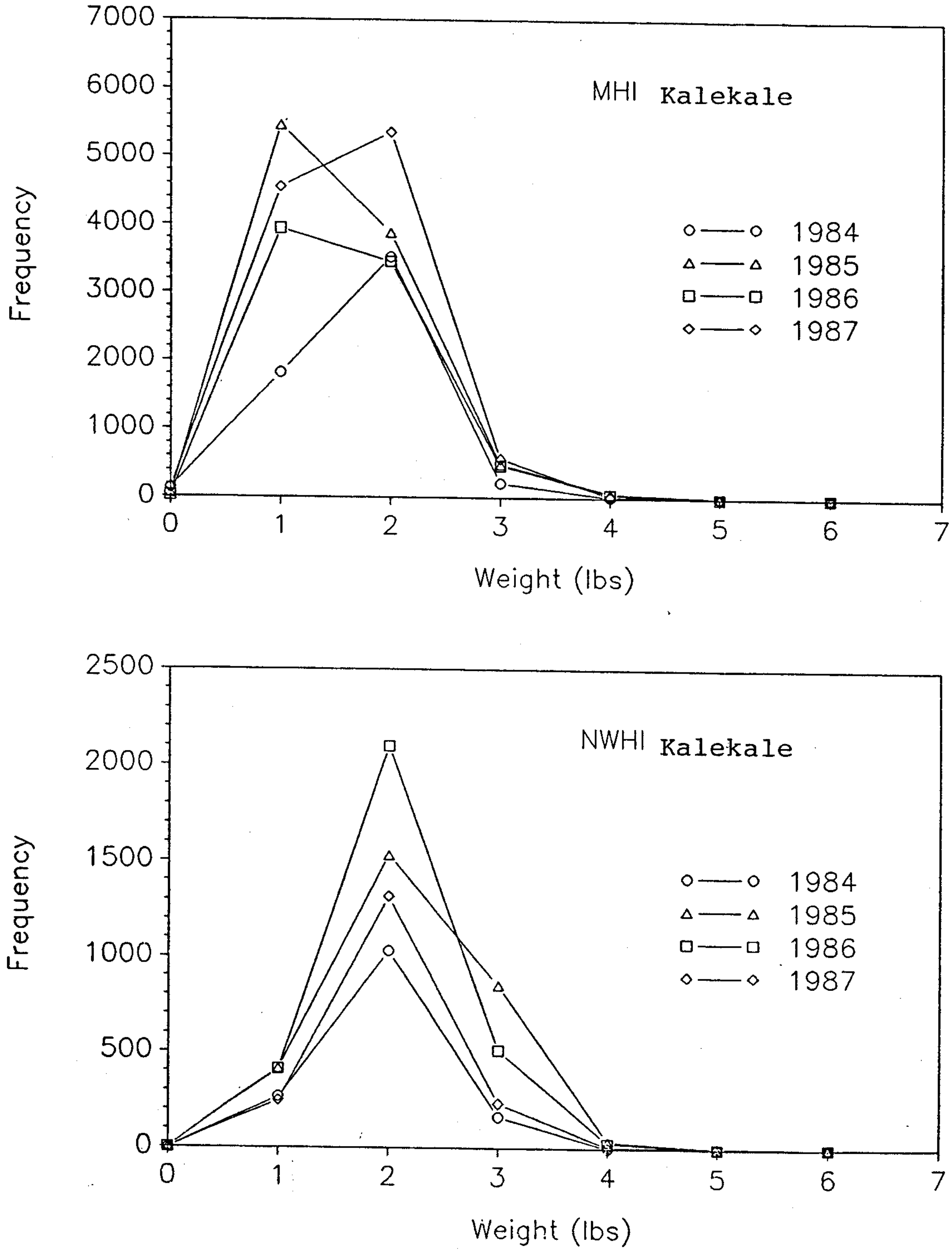


Figure 34.--Weight-frequency polygons for main Hawaiian Islands (MHI) and Northwestern Hawaiian Islands (NWHI) kalekale, Pristipomoides sieboldii. Data are presented for the years 1984-87.

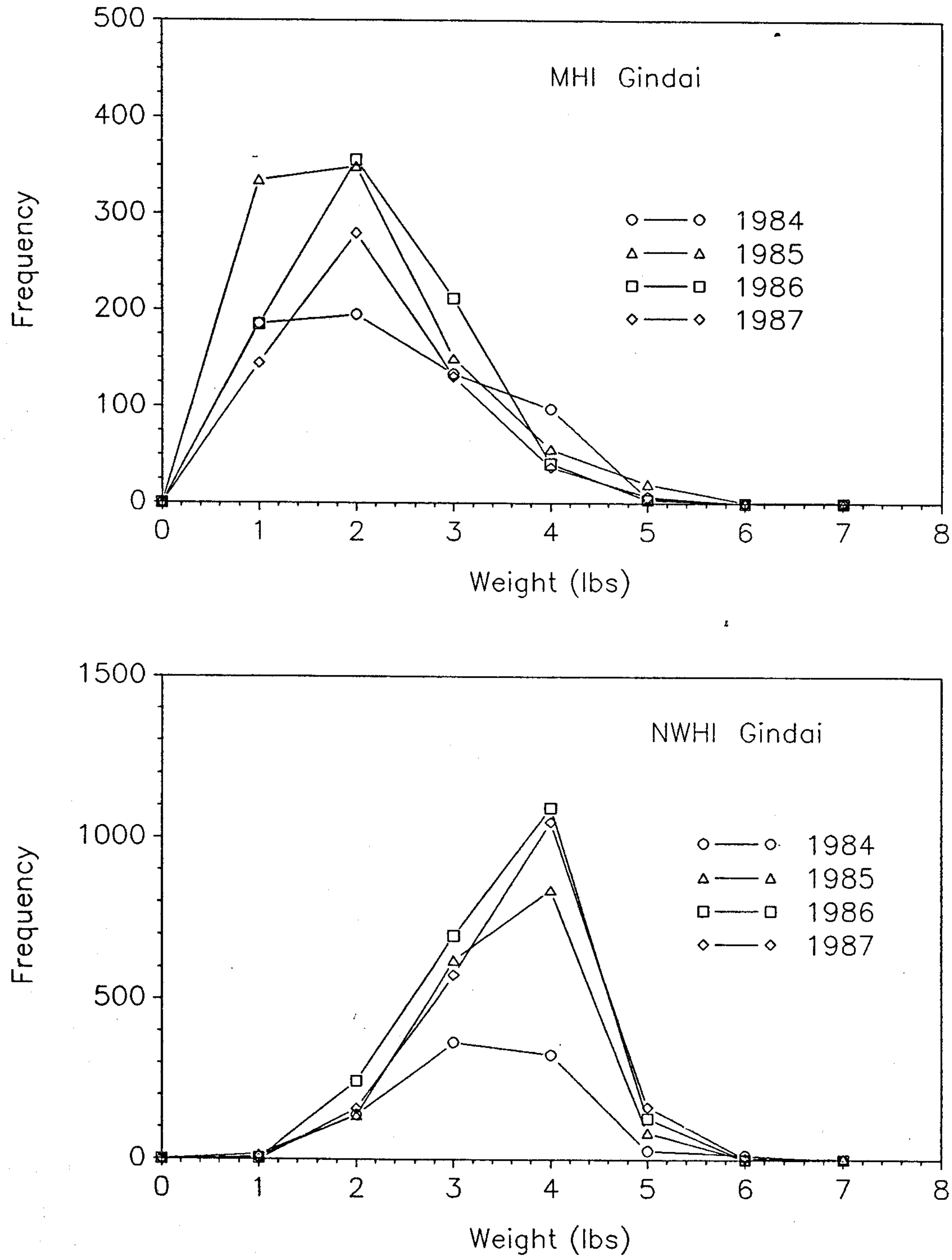


Figure 35.--Weight-frequency polygons for main Hawaiian Islands (MHI) and Northwestern Hawaiian Islands (NWHI) gindai, <u>Pristipomoides</u> <u>zonatus</u>. Data are presented for the years 1984-87.

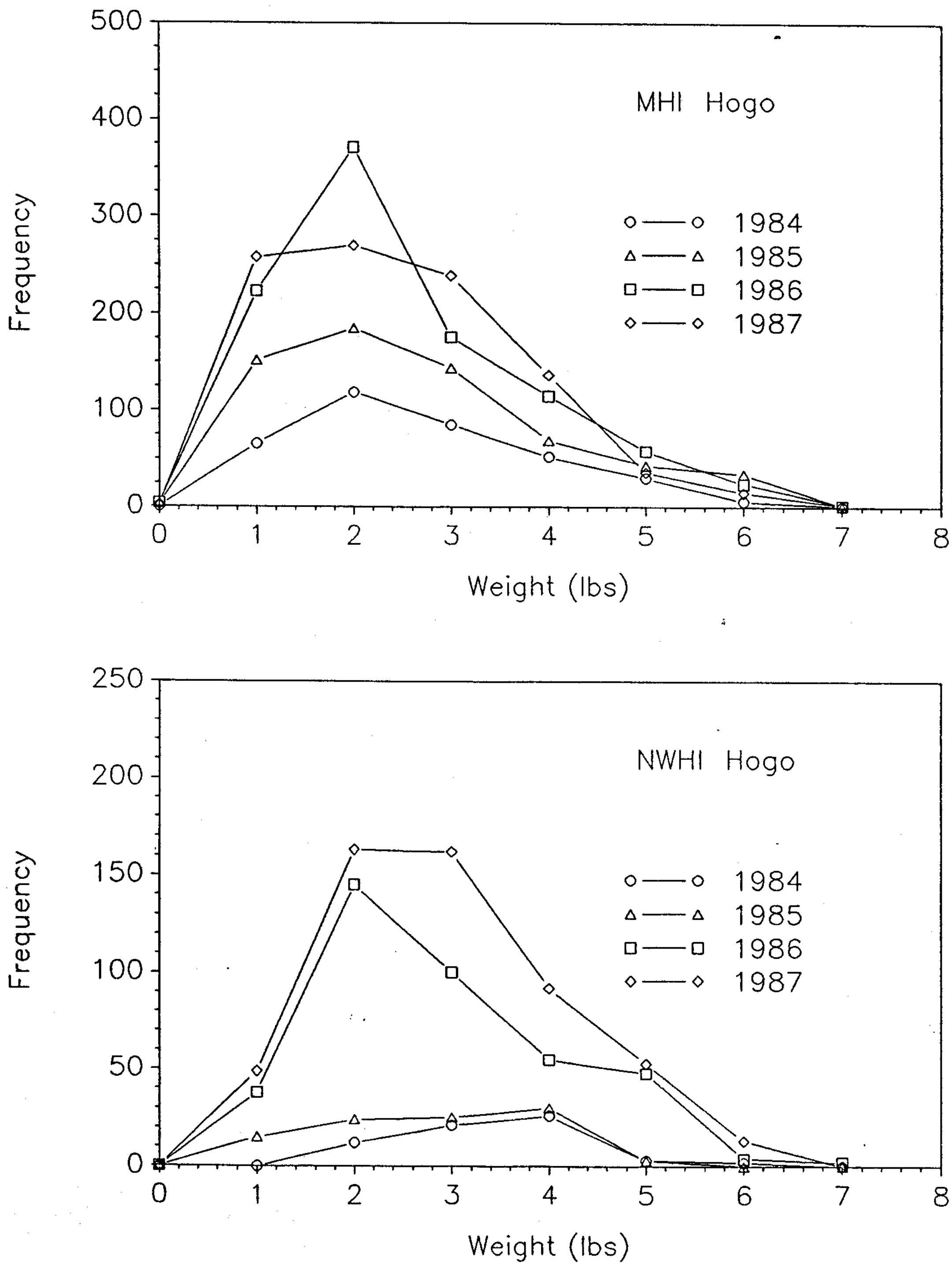


Figure 36.--Weight-frequency polygons for main Hawaiian Islands (MHI) and Northwestern Hawaiian Islands (NWHI) hogo, Pontinus macrocephala. Data are presented for the years 1984-87.

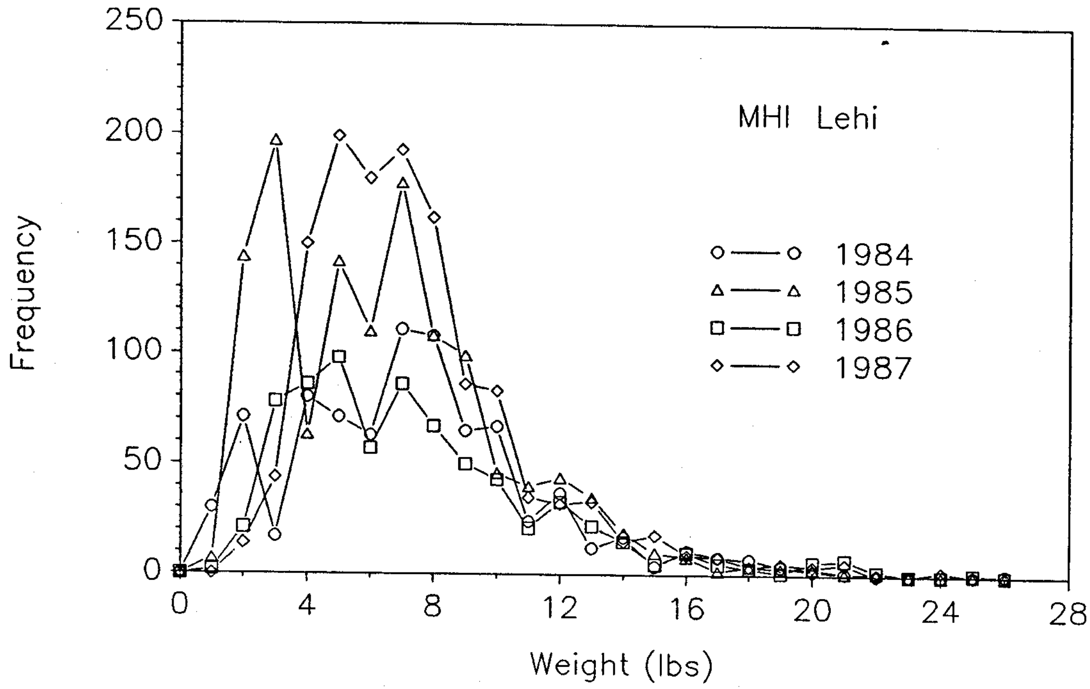


Figure 37.--Weight-frequency polygons for main Hawaiian Islands (MHI) lehi, *Aphareus rutilans*. Data are presented for the years 1984-87.

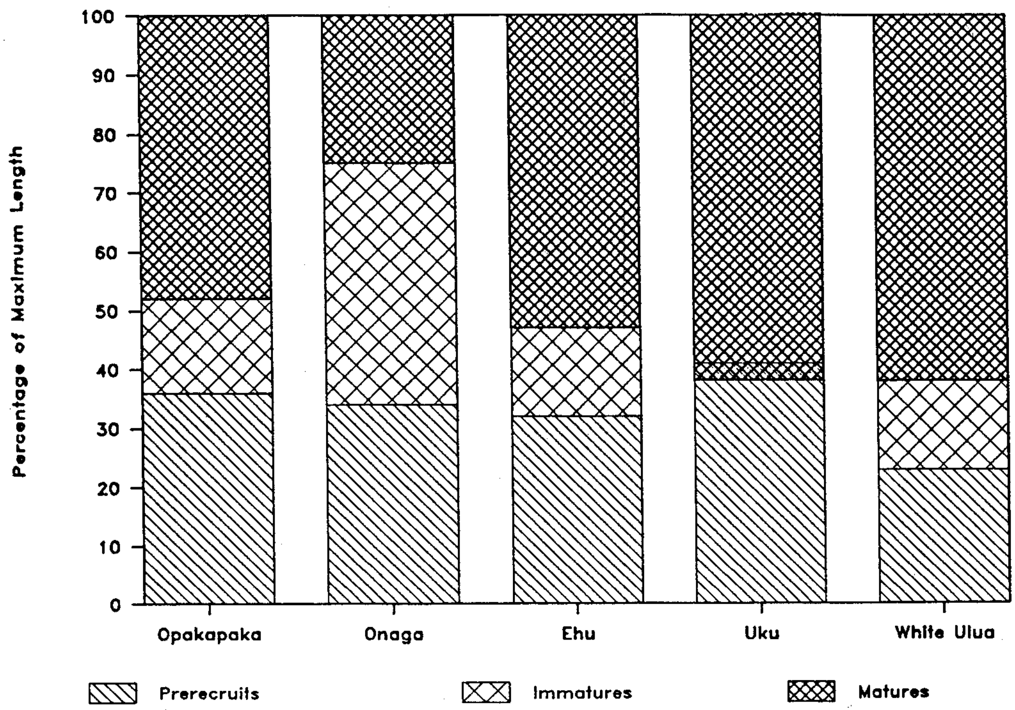


Figure 38.--Relationship of length at entry to the fishery ($\underline{l}_c$) and length at maturity ($\underline{l}_m$) to maximum length ($\underline{L}_\infty$) for five bottom fish species from the main Hawaiian Islands. In each case, the lower "prerecruit" portion represents the lifespan up until $\underline{l}_c$. The middle "immature" portion indicates the range during which fish are harvested but have not had the opportunity to reproduce. The top "mature" portion displays that part of the lifespan during which breeding takes place.